**REUSABLE SPACE VEHICLE GROUND OPERATIONS
BASELINE CONCEPTUAL MODEL**

THESIS

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AFIT/GLM/ENS/04-12

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THESIS

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Abstract

Modeling efforts for future space operation vehicles at the United States Air Force Research Lab's Air Vehicles Directorate have been focused towards the in flight mission. To better serve the research and development effort, a simulation of the ground operations is required allowing for trade-offs within turnaround operations and between the components that drive those procedures. However, before a simulation can be developed a conceptual model must be generated to guide the model building process.

This research provides a baseline conceptual model for reusable space vehicles based on the space shuttle as the only operational vehicle of its kind. The model is built utilizing the Integrated Definition (IDEF) methodology, specifically IDEF3. IDEF3 is focused towards process-viewpoint diagramming and layout. The model is developed using the hierarchical development capabilities of the IDEF3 methodology and is broken into modules allowing for greater reuse and usability.

This model captures the scheduled maintenance performed to turnaround the space shuttle for the next launch but does not contain every activity. The idea was to capture the baseline activities that may be found in future Reusable Space Vehicles and provide a description of what happens at Kennedy Space Center when preparing the space shuttle for the next launch.

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Table of Contents

List of Figures

List of Tables

REUSABLE SPACE VEHICLE GROUND OPERATIONS
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I. Introduction

Overview

The Air Vehicles Directorate (VA) of Air Force Research Laboratory (AFRL) has

focused a large portion of its research and development (R&D) towards the development

of a space operations vehicle (SOV) to support the Air Force's Global Engagement core

competency. Simulation based R&D is one tool used by VA to identify technologies

required to meet Air Force performance requirements. This research will develop a

conceptual model, the baseline for a simulation that will be utilized to perform trade-off

studies of alternative system components and aid in the choice of materials.

In order to develop a model that can be verified and validated, AFRL/VA is

utilizing the space shuttle and an aircraft similar to the B-2 Spirit Stealth Bomber as

baselines. The space shuttle is an example of a successful reusable space vehicle (RSV)

and the B-2 is an example of a system with assets and specialized surface materials

requiring greater inspection time with a relatively fast turnaround. In order to use the

space shuttle as a baseline, the model must include processes/activities from landing to

take-off. The National Aeronautics and Space Agency (NASA) has developed a

simulation for take-off to landing of the space shuttle, however, NASA's touchdown to

take-off (recycling) simulation has insufficient detail to perform technology trade-offs.

AFRL's Human Effectiveness Directorate as well as several defense contractors have

developed simulations for the recycling of SOVs. Unfortunately, the results of trade-off studies vary widely depending upon which alternative was utilized and have not been validated against actual systems. Additionally, the simulations have not been developed to the detail required by VA in order to conduct the analysis they desire.

Problem Statement

In order to develop a detailed simulation for the recycling of the space shuttle, a conceptual model must be developed. The conceptual model provides validation of the processes that are later transformed into a working simulation (Pace 2002). This research will develop a baseline conceptual model for landing to take-off of a generic RSV utilizing the space shuttle ground operations as a guide.

Research Question

What is the best way to provide an effective conceptual model to support the development of a SOV simulation and what space shuttle recycling procedures should be modeled?

Research Scope

The scope of this research involves baseline examinations that include an understanding of conceptual design methodologies. In addition, this study will focus on gathering data on current operations for space shuttle turnaround and a review of proposed SOVs. This study is limited to the current ground operations and logistics for the space shuttle both inside and outside the Orbiter Processing Facility (OPF).

Investigative Questions

In order to address this problem, certain investigative questions were considered.

1. What is simulation based research and development; how does it relate to simulation based acquisition; and how does it support acquisition reform initiatives?

2. Where has the research into RSV development been directed?

3. Process simulation can be used for analysis but requires modeling to delineate the criteria required: What form should this model take and how should it be developed. The following sub questions can be used to evaluate this question.

    o What is the purpose of conceptual modeling?

    o What makes a conceptual model?

    o What are the procedures for developing a conceptual model?

    o What are the procedures for verifying and validating a conceptual model?

    o How have conceptual models been used in the past?

    o What graphical/visualization methods can be used for displaying conceptual models?

4. What are the performance requirements for RSVs that drive the detail level required for model development? The following sub questions can be used to evaluate this question.

    o What procedures comprise ground operations on the space shuttle from landing to take-off: what space shuttle operations would be of interest for the purpose of developing a generalized model for RSVs?

Research into this problem will be directed by a need to answer these questions while keeping the overall objective in mind: development of a baseline conceptual model. The need to produce a validated conceptual model will be paramount to the ability of the model's usefulness in developing future simulations that can be verified. Additionally, an understanding of what components of the turnaround process are important to model development will enable the model to be reduced and made as simple as possible. An understanding of concepts affecting process flows will be necessary in order to gain a better understanding of the operations being examined. In preparing this model, on-site observations of operations and their physical make-up and layout will enhance the understanding of operational flows for the space shuttle in particular.

Summary and Conclusion

This chapter presented background information on and a description of the problem being addressed demonstrating the need for research and analysis. A problem statement was given along with the overarching research objective used to direct the study. Several investigative questions were introduced that will be expanded upon in the following chapters. Chapter 2 will present the motivation for developing a conceptual model and discuss areas of concern when examining a production or maintenance process. Chapter 3 will detail the conceptual model development methodology and present the data analysis methodology. Chapter 4 will explain the data analysis and present the results in the form of a conceptual model. Chapter 4 will finish with a validation of the baseline model followed by Chapter 5 which will provide a brief conclusion and list areas of further research for taking this effort to the next level.

II. Literature Review

Introduction

  Much work is being accomplished to determine what the next generation space vehicle will be and what systems and components would be best suited to serve in this endeavor. NASA is keeping their options open when considering RSVs: either lifting body, winged, or capsule design. For VA, the options considered are all winged. With the space shuttle being the only operational RSV, an effort to develop a conceptual model for RSV ground turnaround procedures would be remiss without heavy concentration on the space shuttle operations at Kennedy Space Center (KSC).

  When reviewing the literature, several topics surface that need discussion when analyzing any process. These areas are as follows: risk management, scheduling, capacity, process management, and layout/location planning. Other areas of interest in this research are acquisition reform (to include simulation based R&D and simulation based acquisition), future/proposed RSVs, and the space shuttle. After gaining a clear understanding of these topics, it is possible to continue this study and develop a useful conceptual model for future RSVs based on the space shuttle.

General Topics

  Risk Management.
Risk Management is defined by the Software Engineering Institute as a practice with processes, methods, and tools for managing risks in a project. It provides a disciplined environment for proactive decision making to assess continuously what could

go wrong (risks), determine which risks are important to deal with, and implement strategies to deal with those risks.

Additionally, DoD Directive 5000.1 "Defense Acquisition" (Department of Defense 2003) mandates a "streamlined management structure and event-driven management process that emphasizes risk management." This includes risks associated with worker safety, environmental concerns such as pollution or chemical spills, and those associated with material trade-offs that might affect crew or payload safety. Additionally, there are concerns for program existence due to mishaps or public opinion. Government funding may be lost or private sponsors and stakeholders may loose interest or possibly want to distance themselves from the program. Public relations can be a significant player in the risk assessment matrix.

In order to include risk management in the decision making process, one must know what the risks are. Several questions can be used to define risks (Cox 2002):

- What is the source of the risk?
- What or who is the target that is at risk?
- What is the adverse effect of concern that the source may cause in exposed targets?
- By what causal mechanism, does the source increase the probability of the effect in exposed targets?

Answering these questions will define possible risks to include the source, who or what is at risk, the "cost" associated with the risk, and any potential causes. However, risk management enters the foray as an external concern. For this study risk management will remain in the background without detailed discussion or examination. Risk management will be more beneficial when conducting trade-off analysis for various components,

systems, and subsystems to be included in whatever RSV is eventually selected. Risk

management will provide the benefit-to-cost ratio used make judgments upon. Various

risks and outcomes could be represented as stochastic distributions within a model in

order to provide a more accurate representation of the real world.

Scheduling.
Scheduling can be defined as "the allocation of resources over time to accomplish

specific tasks" (Krajewski and Ritzman 2001). Conway et al describe scheduling "as the

task of constructing *an ordering of the operations associated with each machine*"

(Conway, Maxwell et al. 1967). With the latter definition comes the idea of sequencing

which is said to exist whenever the order of operation between several tasks is a matter of

choice (Conway, Maxwell et al. 1967). It is clear that many sequencing or scheduling

problems are solved daily and by everyone; however, many do not see or recognize the

choices they make as such. When getting up in the morning, there are several tasks that

are not order dependent—such as brushing teeth, showering, and shaving. Some tasks

such as brushing hair and showering do require a specific order and are thus a sequencing

problem. These examples are quite simplistic in nature and do not require much thought

or planning, but there are more involved problems that have been examined by many and

use various heuristics or sophisticated algorithms to garner near-optimal or optimal

solutions.

Portougal and Robb say that scheduling occurs within various environments with

four characteristic factors: planning level, production type, production strategy, and

production cycle time. The planning level refers to the level within the corporate

hierarchy the planning occurs. Generally, two levels are used formally (company and

shop floor) with the aggregate level being conducted informally between the two

(Portugal and Oliver 1996). Production type refers to relationships between variety,

volume, and process. The next characteristic, production strategy, refers to the choice

between make to order and make to stock. Production cycle time is the last

characteristic, and is the key to determining whether scheduling theory is applicable and

would be beneficial to planning and scheduling (Portugal and Oliver 1996).

Based on their research, Portougal and Robb suggest only systems with long cycle

environments would benefit from scheduling theory applications to the more complex

nature of processes with cycle times longer than the planning period. When a process can

be completed within its planning period, scheduling is less complicated and does not

require the aid of sophisticated algorithms. Portougal and Robb base this conclusion

partly on the fact that all theoretical scheduling problems assume long-cycle

environments suggesting a disconnect between what is seen in practice and what is

proposed and analyzed in research (Portugal and Oliver 1996).

Scheduling is similar to a job shop method since the operations at KSC involve

the space shuttle remaining stationary within the OPF with maintenance personnel

coming to the shuttle. Although the shuttle remains stationary during the maintenance

effort, some components are removed and taken to other facilities for further processing.

Much of the scheduling will be constrained by various facilities with limited space, level

of hazard or risk, and number of personnel or by personnel who perform certain tasks.

Within a work or process flow is the sequence of operations or tasks guided by

various constraints. The routing scheme is the path or flow that is followed. This scheme

can either be mandatory (all steps are prescribed and followed in specific order) or

flexible (several alternative flows are allowed as long as the constraints are not violated).

The shuttle operations would involve a mix of both routing schemes. There are some

tasks that are prerequisites to others and some that are performed in parallel and others

that can be performed at any time within the turnaround cycle (Kumar and Zhao 1999).

Each vehicle is prepped for a preplanned mission and various inspections being

completed based on the previous mission. An example would be the use of additional

internal (inside the cargo bay) tanks used by the shuttle to extend missions. Not all

missions would require the tanks and thus slightly different procedures would be used.

However, much of the turnaround operations would be the same for every mission

assuming no unforeseen problems or failures.

Capacity.
Scheduling, layout, and resource allocation all have some affect on or are affected

by capacity. Portougal and Robb list four definitions for capacity that they have

observed.

- Design capacity: the maximum output that a production unit (PU) has been designed to produce.
- Effective capacity: the maximum possible output given a particular production environment and its accompanying impediments to productivity.
- Demonstrated (historical) capacity: the typical real-life output rate of a PU.
- Agreed capacity: the actual capacity negotiated between directors of PU (Portugal and Oliver 1996).

Krajewski and Ritzman (2002) list three types of capacity they call peak capacity

(maximum output a process or facility can produce under ideal conditions), rated capacity

(an engineering assessment based on continuous operation with allowance for normal

maintenance and repair time), and effective capacity (the maximum output a process or

9

firm can economically sustain under normal conditions). Capacity can either be a constraint in the case of bottlenecks or can be a tool to limit the affects of variability in the case of excess capacity. Sometimes additional resources or capacity are maintained for periods of increased demand. Safety stock is an accepted method to protect against variable demand or scarce resources during periods where demand fluctuates. For the military, this might concern the keeping of certain aircraft or personnel in order to meet the requirements of current defense and national security policies. The result here is excess capacity and increased costs that require justification during the trade-off analysis.

Process Management.
Much of the previous discussion falls beneath the umbrella of process management. Process Management is "the selection of the inputs, operations, work flows, and methods that transform inputs into outputs" (Krajewski and Ritzman 2001). A process is defined as "a series of activities that produce a product or service" (McNeese and Marks 2001). Input selection would include make or buy decisions, operations selection would involve the choice of process, resources, and layout decisions although the latter may be a one time decision. Process management would, however, focus on ongoing decisions made on a somewhat regular basis. Process management:

- focuses on the management of processes, not departments
- includes primary, secondary, and work (or sub) processes
- seeks to optimize performance of the entire system
- ensures processes are standardized
- ensures measurements support the vision
- ensures best practices are examined
- focuses on customer satisfaction
- ensures continuous improvement and measurable value

- represents the way the company is (McNeese and Marks 2001)

Workflow management involves the coordination and control of processes and activities of people and systems in an organization (Kumar and Zhao 1999). Workflow management involves information processing and business processes two of three activities conducted in a business; the third is material processes. Process management would cover the third activity. Although the two seem to be complementary, there are many similarities as to how they handle their basic tasks and operations. To some degree, workflow management will have its greatest benefit in the feedback loops that allow for improved communication.

Process management has within its scope such techniques as total quality management and continuous improvement. There are five common elements of process management success (Ittner and Larcker 1997):

- process focus
- human resource management practices
- information utilization
- customer/supplier relations
- organizational commitment

Process focused management lends itself towards improvement and organizational structures based on functions or processes. Human resource management practices that lend themselves towards greater training and education as well as a team-oriented environment are better suited towards process improvement. Information utilization deals with the reduction of variability and waste through the facilitation of problem solving. An emphasis on workflow management could enhance the utilization of

11

information. The last two areas deal with improved supply chain relationships and with

senior leader involvement. The first three items relate more to this research based on its

process oriented view and the underlying consideration of human resource management

practices and policies that affect the flow and are not inherently evident.

Layout/Location Planning.

When considering location there are several aspects to examine—such as where

to locate based on resources available, environmental concerns, and type of orbit desired.

The layout of facilities, and within-facilities, concerns the actual physical layout at the

chosen location. Depending upon various physical features, the physical layout at a

chosen location (such as topography) could have significant effect on possible facility

layout.

The layout of various work centers and facilities could become the source of

constraints as well as the lack of available resources due to location choice. According to

(Krajewski and Ritzman 2001), layout choices can affect:

- flow of materials and information
- utilization of labor and equipment
- customer convenience and sales
- worker safety
- worker morale
- communication

Four types of layouts are used in general.   The first is the product layout in which

a linear path is used between workstations and departments. This layout is well suited to

repetitive or continuous production. The second type is the process layout where

grouping of workstations or departments is accomplished by function. This layout is well

suited for low volume environments typical of job shops. In some cases, a mixed or hybrid layout is used. This layout combines some aspects of the process and the product layouts to achieve operational goals. The last type of layout is the fixed-position layout.

In the case of the shuttle, only two locations were considered for possible launch sites (Vandenberg AFB, CA and KSC) with KSC being the only location ever used. This decision was based in part on the facilities already present, but, topography played an important role. For these locations, their positions near a large bodies of water where launches could take place over non-populated areas and allowed for the possibility of easterly orbits from KSC and polar orbits from Vandenberg (Graham and Jones 1982).

Weather considerations were also considered since poor weather can result in delays depending on facility choices and will affect launch and return dates most. Most of the assembly occurs within various facilities and structures protected from the effects of weather. A real concern at KSC is the hurricane season, though this does not happen often enough to drastically affect operations. However, ground ops at KSC would not be hindered by weather since assembly occurred out of the elements.

Acquisition Reform

The DoD has moved from a bottoms-up to a top-down approach to determine capability requirements. The newly released DoD Directive 5000 Series document the new approach to system acquisition including emphasis on joint capabilities, teamwork, lifecycle cost, and best practices. Acquisition Reform Initiatives support the DoD's need to acquire new capabilities quickly and control/reduce life cycle costs.

In order to transition to this new business model, the Air Force developed

initiatives such as Cost as an Independent Variable, Lightning Bolts, Reduction in Total

Ownership Cost and Lean Aerospace Initiative. These initiatives present methods to

reducing total ownership cost, total cycle time, and provide tools to successfully acquire

new Air Force capabilities quickly at an acceptable cost.

Simulation Based Acquisition.
Simulation Based Acquisition (SBA) is a concept where an integrated,

collaborative process is used for planning and execution of an acquisition program. SBA

is a collaborative environment where all parties involved in the acquisition process work

together, independent of the physical location, to solve problems and develop processes

during all phases of acquisition.

SBA is seen as a tool for the program manager which will reduce risk in cost,

schedule and performance through (Fallin 1997):

- Continuous evaluation of system development.
- Rapid evaluation of concept design.
- Reduce and delay need for physical prototype.
- Facilitate continuous user participation in development process.
- Efficient development/evaluation of manufacturing plans.
- Reuse of system software and hardware in training simulators.
- Ability to test proposed system at sub-component, component, and system level.

The effectiveness of SBA versus standard acquisition methodology was tested in

a study performed at the Defense Systems Management College (Brown 1999). An

acquisition project was developed to design, manufacture, and test prototype vehicles

meeting a specific set of manufacturing and performance criteria. The students of the

Advanced Program Management course (APMC) were divided into groups, one of which was a control group.

Each group was provided with an Operational Requirements Document and Statement of Work. Each group received the same materials with the exception of software. The control group was provided with standard modeling software used in previous APMCs including information relative to one system requirement. This software model included only basic design equations. On the other hand, the advanced groups were provided an advanced design and simulation tool that not only evaluated design for performance, but also relative to cost, weight, and producability.

Though on average, the additional modeling and simulation (M&S) cost drove up the concept development and demonstration costs, from a total life cycle perspective simulation based acquisition delivered a more mature, producible design. The author did note one drawback to M&S. When a competitive environment was added to the mix, the group used M&S to "gain a competitive advantage, not to reduce development cost and schedule." Figures 1-4 show the results of this study.

Producibility Index (PI) = (# types of parts) * (# total parts)
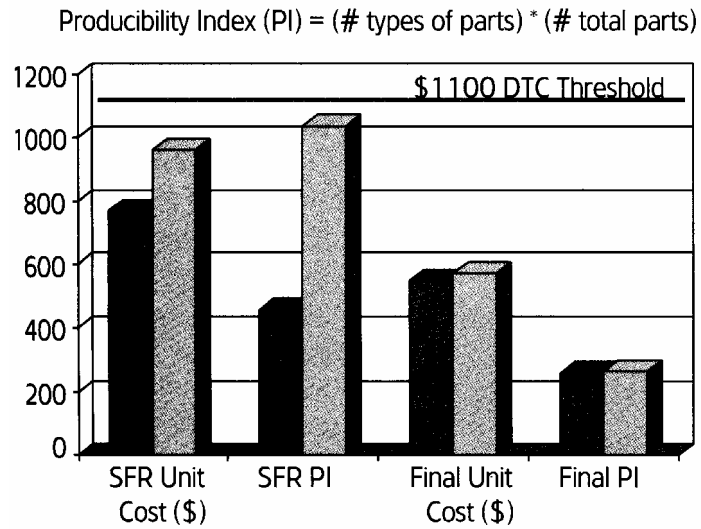
Figure 1. Cost/Producability Comparison

(Brown 1999)
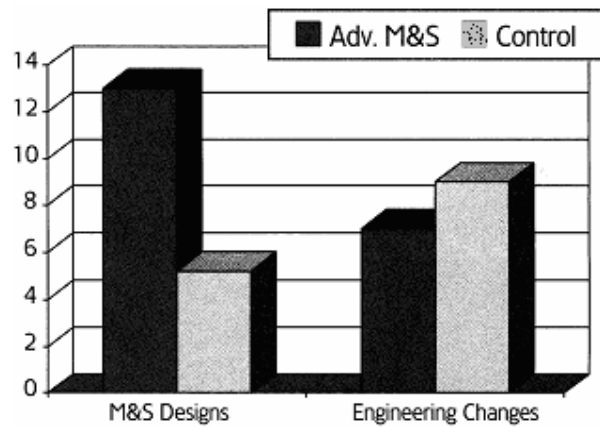
Figure 2. Development Comparison

(Brown 1999)
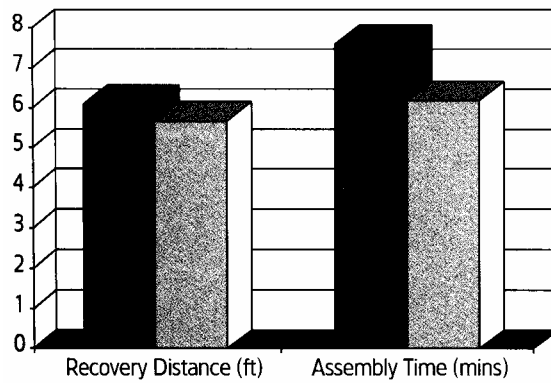
Figure 3. Performance Comparison

(Brown 1999)
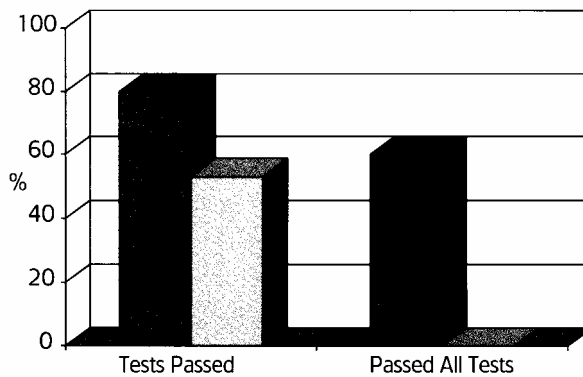
Figure 4. Runoff Comparison

(Brown 1999)

Simulation Based Research & Development.
Simulation based Research & Development (SBR&D) is a methodology that

utilizes a common computer environment for the development of new aerospace concepts

prior to Milestone B, concept development through design to testing (Air Force Research

Laboratory 2002). SBR&D therefore supports the DoD's Integrated Product and Process

Development (IPPD) management process and its use of multidisciplinary teams to

17

optimize the design, manufacture, business, and supportability.   IPPD emphasizes

concurrent development of product and processes, early and continuous life cycle

planning, multidisciplinary teamwork, proactive identification and management of risk

(Department of Defense 1999).

SBR&D combines a variety of M&S as well as research and technology-

development tools (engineering-level modeling, design, and analysis tools, mission-and

campaign-level simulations, cost analysis tools, and database tools) into a common

computer environment (Zeh and Schumacher 2001). Through the integration of these

tools, a common synthetic battlespace is developed (Zeh and Schumacher 2001). New

and current aerospace systems can be inserted into the battlespace where cost and

performance trade-off studies are accomplished to evaluate the potential benefits of new

technology capabilities. The three primary goals of SBR&D are (Zeh and Schumacher

2001):

- *Guide Air Force Science and Technology (S&T) investment*
- *Reduce R&D time and cost to develop and mature promising technologies*
- *Integrate the Warfighter and technologist into the S&T acquisition process.*

Future Reusable Space Vehicles.

An on-going effort to demonstrate the possibility of creating a quick turnaround

spacecraft for commercial use has been underway under the title: X-Prize. This

competition is based on previous competitions of the past that gave monetary prizes to

the first individual or group that completed a specific event, such as a non-stop solo flight

across the Atlantic Ocean. Although Lindberg received $25,000 for his feat, the X-Prize

is set to award $10,000,000 for the first to fly a vehicle to a height of 62.5 miles above the earth with three passengers (or one pilot and the equivalent weight of two passengers) and repeat the event within 14 days. The amount of prize money and purpose for the competition is in part designed to generate public interest in space flight (CNN 2003). Table 1 provides an overview of the various take-off and landing scenarios under development for the X-prize competition as well as the number of stages considered. Table 2 provides a brief overview for the commercial and public sectors vehicles.

Table 1. X Prize Contenders

Take-off Scenario	Qty	Landing Scenario	Qty	# Stages	Qty
Vertical	8	Vertical	1	Single	5
Horizontal	4	Horizontal	11	Two	2
Carrier craft	8	Parachute/foil	6	Multiple	1

. (FAA 2000)

Table 2. Public and Private Sector RSVs

Take-off Scenario	Qty	Landing Scenario	Qty	# Stages	Qty
Vertical	8	Vertical	1	Single	5
Horizontal	4	Horizontal	11	Two	2
Carrier craft	8	Parachute/foil	6	Multiple	1

(FAA 2000)

Much of what is under development is for commercial use whether it is for space tourism, payload delivery, or a combination of both. The key problem to successful implementation of a commercially viable vehicle is the reduction of cost (Kaplan 2002). One of the areas driving up the cost for RSVs is the cost per launch. One way to reduce this cost is to enable faster turnaround and increase the number of available launches. Even the space shuttle was initially projected to have much shorter turnaround times than what currently exists.

The shuttle was initially planned to have 40 missions per year and have a turnaround time of 160 hours(Jenkins 2002). Before the Challenger incident in 1986, the shuttle was on target for 16 missions. After Challenger, the target has settled down around seven and may decrease once more after Columbia. The current thought on launch vehicles is to have turnaround times as short as 48 hours with a 24 hour surge capacity with times no longer than 14 days. The Air Force in particular is looking for high sortie rates in the neighborhood of 20 per two-week period (Wall 2002). Additionally, many of the concepts call for smaller crews to handle the turnaround operations especially as compared to the numbers surrounding space shuttle operations.

Much of the literature on RSVs focused on the information contained in Tables 1 and 2 above. Additionally, discussions have begun to look at the support and ground operations of RSVs. Since no specific type of vehicle has been selected as the "one" design to develop, this research will not focus on anyone type nor leave out components that may be space shuttle unique.

III. Methodology

Overview

The overarching design behind this research is a case study lending itself to task and contextual analysis. This study will focus on the ground operations of the space shuttle as an example of RSV operations. Being inductive in nature, this study will be concerned with the construction of a descriptive model. No intent is given at this point to compare alternatives only to examine the processes as they currently exist and provide a description in the form of a conceptual model.

This chapter will discuss conceptual models and what is required to present a useful model. The need for a model, its purpose, and its characteristics will be discussed. Additionally, the methodology chosen for the layout, documentation, and building of the conceptual model will be presented followed by a brief examination of how the data will be handled. A detailed analysis of the data and how the conceptual model was built will be presented in Chapter 4.

Conceptual modeling

A conceptual model aids in scope of reuse and in the development of simulation models created from the conceptual model. The value of quality conceptual model can be seen in the fact that some simulation requirements may be "incomplete, unclear, inconsistent, and sometimes wrong" (Pace 2002). A conceptual model provides a great benefit for the simulation developer but is still hampered by the experience and knowledge of the builder. "Regardless of how it is defined, model conceptualization is

considered as much an art as a science" (Rohrer and Banks 1998). The goal is to reduce

the multitudes of data to useable and manageable pieces that are separate from the noise

and other distractions. A certain but not easily definable level of abstraction is desired

from the process. Benjamin et. al. list three levels of abstraction to aid in simulation

model development: (i) Domain Level, (ii) Model Specification, and (iii) Execution and

Analysis Level (Benjamin, Delen et al. 2000).

 The Domain Level includes information about processes and their relationships.

The descriptions may either be process-oriented or object-oriented. The Design Level

contains information needed to build the simulation model such as input requirements,

experimental design requirements, and data required to build the simulation. The final

product from this level is the actual simulation. The last area, Execution and Analysis

Level, includes the input data and its analysis, the simulation runs, and output from

experimental runs. The output from this level is the results of the simulation runs and

conclusions made based on the analysis that follows execution. This may include

decisions on various trade-offs. The following figure illustrates the three levels.
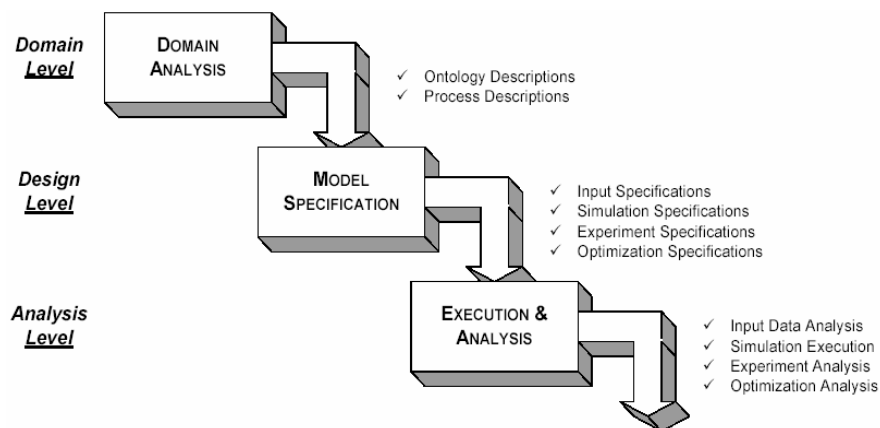
Figure 5. Separation of Levels Extends Reuse Scope

(Benjamin, Delen et al. 2000)

22

As can be seen in this diagram, the Domain Analysis is accomplished before

specifying a simulation model and gathering detailed information about input data and

experimental design. This level is just a basic representation of the system to be modeled

and the major components. Therefore, the focus of this research effort will be on the

Domain Analysis Level providing ontological and process descriptions as necessary.

Purpose
Economic considerations exist emphasizing the importance for reuse of

simulation components (Pace 2000). Considering the cost of model development, it is

wise to develop models based on previous work or that have multiple uses. For example,

NASA's GEM-FLOW is a generic simulation used to model the launch and in-flight

operations of various spacecraft to include traditional lift vehicles and the space shuttle.

A documented conceptual model aids in reuse or use in combination with other

simulations by allowing others to know the background of the model allowing clearer

understanding of its limitations and intended purpose. The construction of a conceptual

or structural model is typically carried out by an analyst as an undocumented thought

process rather than as an explicitly represented design activity (Benjamin, Delen et al.

2000). Simulations created in this ad hoc manner, often, do not include documentation of

the conceptual model if it even existed in the first place. As a result, problems are

created for the future use of the simulation since the final executable simulation is the

only documentation.

Description
Conceptual models tell the customer what the system will do. A conceptual

model translates modeling requirements into a detailed design framework (Pace 2000)

and is the collection of information that describes a simulation developer's concept about

the simulation and its pieces (Pace 2000). It is the primary mechanism for clear and comprehensive communication among simulation developer and implementation personnel (Pace 2000). There are several questions that can be answered by a conceptual model (adapted from (Pace 2000).

- What objects will be in the system?

- What will happen to the objects in the system?

- What will the system look like to simulation developers?

- What choices will be offered to simulation developers?

- What is the timing of events?

- What will the output look like?

A conceptual model is the framework upon which a simulation will be built. When more than one simulation is interconnected into a system it is called a Federation of Models and Simulations and the simulation is referred to a Federate (Department of Defense 2003). Conceptual models have been used for the development of databases, software programs, and clarifying and describing processes leading to the development of a simulation model. However, a conceptual model can itself be an end product used primarily for the purpose of description.

The characteristics of a good conceptual design include the use of customer language not jargon, system function descriptions, implementation independence, and linked to requirements linkage. A conceptual design is different from a technical design in that the latter tells programmers what the system will do and includes major hardware components and their function, hierarchy and function of software components, data structures, and data flow.

A conceptual model should contain three components: simulation context, mission space, and simulation space (Defense Modeling and Simulation Office 2000; Pace 2000). The simulation context contains the laws of physics and principles of engineering included in a physical model. Mission space refers to simulation elements: entities, assumptions, algorithms, characteristics, relationships, and data. The simulation space contains additional information "needed to explain how the simulation will satisfy its objectives" (Pace 2000). The mission and simulation space are both part of the simulation concept. These components can be seen in Figure 6 below:
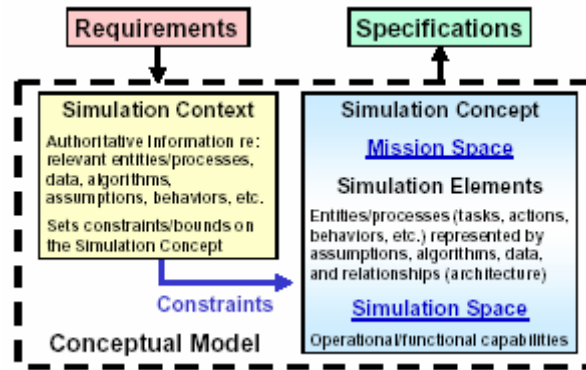
Figure 6. Conceptual Model Components
(Defense Modeling and Simulation Office 2000; Pace 2000)

Several design steps for conceptual models have been put forth by various authors. Benjamin et al suggest the following steps: (i) Determine the specific goals of the simulation study: what is the objective? (ii) Determine the object roles, boundary and level of detail selecting the part to be studied, level of abstraction, and identify model objects and roles (Defense Modeling and Simulation Office 2000; Pace 2000).

Pace suggests the following design steps (Defense Modeling and Simulation Office 2000; Pace 2000). First, the model builder needs to collect authoritative info

about the context. This involves creating authoritative descriptions of entities, processes,

and situations. It "should address everything needed to fully describe the domain of the

simulation" (Defense Modeling and Simulation Office 2000). When less is known about

the context, the effort becomes more difficult. The next step is to identify entities and

processes referred to as decomposition of the mission space. This step is where decisions

are made about the level of detail and drill-down and can help the model stay with the

established scope. The following lists several principles of decomposition:

- There should be a specific simulation element (parameter, entity, etc.) for
  every item (parameter, entity, etc.) specified for representation in the
  simulation by simulation requirements.

- There should be a specific simulation element (parameter, entity, etc.) for
  every item (entity, task, parameter, state, etc.) of potential assessment
  interest related to the purpose of the simulation.

- There should be "real world" counterparts (objects, parameters for which
  data exist or could exist, etc.) for every simulation element as far as
  possible. The potential impact of data, and metadata structures, on
  simulation elements and the simulation conceptual model should not be
  underestimated.

- Wherever possible, the simulation elements should correspond to
  "standard" and widely accepted decomposition paradigms to facilitate
  acceptance of the conceptual model and effective interaction with other
  simulation endeavors (including reuse of algorithms and other simulation
  components).

- Simulation elements required for computational considerations (e.g., an
  approximation used as a surrogate for a more desirable parameter that is
  not computationally viable) that fail to meet any of the previously stated
  criteria should be used only when absolutely essential.

- There should not be extraneous simulation elements. Elements neither
  directly related to specific items in the simulation requirements nor
  directly implied by potential assessment issues and elements without a
  specific counterpart in the real world or in standard decomposition
  paradigms should not be included in the simulation conceptual model.
  Every extraneous simulation element is an unnecessary source of potential

simulation problems (Defense Modeling and Simulation Office 2000; Pace 2000).

The third step involves developing simulation elements necessary for each entity or process detailed in the previous step. "Simulation elements determine functional and behavioral capabilities of the simulation" (Defense Modeling and Simulation Office 2000). The last step is to define interactions and relations among simulation elements ensuring all the relationships among simulation elements are addressed. Additionally, all constraints and boundaries set by the domain should be imposed and expressed within the requirements (Defense Modeling and Simulation Office 2000; Pace 2000).

When laying out the model, it is best to keep it structured and modular allowing for more flexibility and more rapid development (Rohrer and Banks 1998). Although the process of abstracting from reality can be difficult, it is best to have some structured approach guiding the process.

Documentation

The documentation should provide a "coherent set of information that fully and correctly describes the conceptual model so that its capabilities, limitations, and characteristics can be readily understood by simulation development personnel; verification, validation, and accreditation personnel; and by subject matter experts involved in simulation assessments" (Pace 2000).

When completing the project, there are several items to include in final product which include the following:

- A write-up about the various sub-systems in the system
- A set of conceptual drawings of the main individual components

- A technical description for the complete system, explaining the function of the system

- Detailed costing and commercial aspects for development of the complete system

- Recommendations

Visualization

Knowing what a conceptual model is and what to include still leaves one question unanswered: What graphical/visualization methods can be used for displaying conceptual models? A simplistic method would be the use of flowcharts describing the entities, processes, and flows through the overall process, but this method might not capture the full dynamics of the system. Flowcharts would be best suited as an initial step in development for gathering ideas and laying out a general flow—such as an activity diagram (Cochran and Wheaton 2002). Still another methodology exists that not only provides for the visualization of the model, but satisfies the requirements discussed in this chapter for the development of a quality conceptual model.

Integrated Definition (IDEF) Model

The methodology that satisfies all the requirements for conceptual model development is IDEF3. IDEF began as an Air Force program for Integrated Computer-Aided Manufacturing (ICAM) where the first ICAM Definition was created and later recast as it currently stands with several versions now available (Mayer, Menzel et al. 1995). IDEF was initially created to be a set of methodologies that would represent manufacturing systems. The first set of IDEF methodologies, IDEF0, IDEF1, IDEF2, and IDEF3, were developed for functional, data, dynamic analysis, and process modeling, respectively (Kusiak and Zakarian 1996).

28

IDEF0 is used to model flows with an emphasis on decisions and actions. IDEF 0 allows for process descriptions with the inclusion of control mechanisms that affect and direct the flow of information or objects. IDEF1 was designed to be used with software and communication model development and analysis. IDEF2 provides for the description of dynamic systems but leaves out guidance on graphical representations allowing the user to develop models using language-specific figures. IDEF3 provides for process modeling in addition to object-oriented views. Several other methods are under development or being proposed but are not geared towards process modeling which is important to this research effort.

Of the IDEF methods listed above, IDEF0 and IDEF3 provide the most possibilities; however, IDEF3 provides the most functionality and is better suited towards the development of a conceptual model of physical processes. The Table 3 summarizes some key attributes of a conceptual model and how it is addressed by a IDEF3 model detailing how an IDEF3 model meets the criteria of a conceptual model.

Although IDEF3 satisfies the ability to develop ontological in addition to process descriptions, another methodology, IDEF5, has been developed to build ontological descriptions. The difference is that IDEF3 provides a means for describing processes to include precedence, object flow, and relational links (Kusiak and Zakarian 1996) and for the description of entity state changes detailing the processes involved. Being a more capable methodology, IDEF3 has been chosen for this research effort. The following table will compare the IDEF3 methodology to the attributes of a conceptual model. The chapter will continue with a description of IDEF3 components and a brief explanation of the development process.

Table 3. Comparison of Model Attributes

| Attribute | Model | |
	Conceptual	IDEF3
Domain Analysis		
	- Ontology Descriptions - Process Descriptions	- Satisfies Domain Level analysis which is comprised of ontological and process descriptions.
Validation (appropriateness)		
Completeness	- 1/1 entity to process ratio - Simulation space components addressed - Satisfies specifications for simulation	- Requires one unit of behavior (UOB) or object symbol for every activity/process or object, respectively - Allows for more data in the form of notes, elaborations, file attachments, and description addressing simulation space and specifications
Consistency	- All perspectives are compatible	- Allows for both object-oriented and process-oriented views utilizing the same components
Coherence	- All elements have a function and can be activated	- All elements must have a real world counterpart
Characteristics		
	- Functional descriptions - Generalized language; no jargon	- Functional descriptions - Terminology set by the modeler
Three components		
	- Simulation context (physical constraints) - Mission space (entities, assumptions, relationships, etc.) - Simulation space (additional information needed to identify how the simulation will satisfy objectives)	- Physical constraints set by links - UOBs and other schematic symbols cover all entities, etc.; notes, elaborations, etc. cover assumptions - Elaborations, notes, descriptions, and file attachments allow for addition of more data
Documentation		
	- Subsystem write-up - Conceptual drawings - Technical system description	- Decompositions allow for subsystem inclusion in a hierarchical format - IDEF3 schematics - Elaborations, notes, descriptions, and file attachments
Viewpoints		
	- Event-oriented - Object-oriented	- Event-oriented - Object-oriented

IDEF3

IDEF3 was created to capture descriptions of sequences of activities with the primary goal of providing a structured method by which operational and system knowledge can be expressed (Mayer, Menzel et al. 1995). An IDEF3 model serves to detail the simulation context and simulation concept. To achieve this goal, an IDEF3 model must support the items the following list (adapted from (Mayer, Menzel et al. 1995).

- Scenarios of organizational activities.

- Roles of entity types in the organizational activities.

- Entity scenarios or entity interaction with the system at the entity-function level.

- System response to entity functions.

- Entity classes and delineation of entity classes.

- Declaration of timing, sequencing, and resource constraints.

- Entity interface objects (e.g., tools, test equipment, and facilities)

Several software packages have been produced that produce IDEF products. Meta Software's Workflow Modeler produces IDEF0 diagrams. IDEFine Ltd has developed software to work with IDEF0 and IDEF1x. However, neither of these would be useful in this endeavor since they do not work with IDEF3. For this work, three software packages were examined. Knowledge Based Systems, Inc.'s (KBSI) ProSim, Computer Associates International's AllFusion: Process Modeler, and Popkin Software's System Architect. All three produce IDEF3 products with the latter two working with IDEF0 as well. Of the three, ProSim was the most user-friendly providing a graphical interface and capability for exporting to MS Visio, MS Project, and HTML coding for

use in any web browser. KBSI is the prime contractor for the Armstrong Laboratory, Human Resources Directorate, Logistics Research Division, Wright-Patterson AFB, OH for the development of IDEF software, ProSim. According to KBSI, the following are uses of the IDEF3 methodology (Mayer, Menzel et al. 1995).

- Record the raw data resulting from fact-finding interviews in systems analysis activities.

- Determine the impact of an organization's information resource on the major operation scenarios of an enterprise.

- Document the decision procedures affecting the states and life-cycle of critical shared data, particularly manufacturing, engineering, and maintenance product definition data.

- Manage data configuration and change control policy definition.

- Make system design and design trade-off analysis.

- Provide simulation model generation.

IDEF 3 Models have been used for the development of conceptual models (Cochran and Wheaton 2002), reliability evaluation (Kusiak and Zakarian 1996), and simulation development (Benjamin, Delen et al. 2000) as well as business process reengineering but is not limited to these efforts. The IDEF3 methodology does not capture all aspects of the system though it can be used in conjunction with other methods to provide a very detailed description. Although other methods can be added, it is essential to stay within the scope of this research and focus on the description of the processes and development of the conceptual model keeping efforts within the scope of Domain Analysis.

Benefits of IDEF3 Methodology
Some benefits of the IDEF3 methodology are realized through its ability to identify obscure process links, highlight redundant and/or non-value-added activities, and

speed the design of new processes. Some of the benefits realized by the use of the IDEF3

methodology are listed below.

- Capture and distribute detailed manufacturing process knowledge (e.g., Hubble telescope mirror fabrication process) among geographically dispersed units.

- Determine the impact of an organization's information resource on the major operating scenarios of an enterprise.

- Provide an implementation-independent specification for human system interaction.

- Define data configuration management and change control policy.

- Document the decision procedures affecting the states and life cycle of critical shared data.

- Speed the development of high quality IDEF function models.

- Speed the development and validation of simulation models.

- Develop real-time control software by providing a mechanism to clearly define facts, decision points, and job classifications.

- Define the behavior of workflow management systems and applications.

- Prescribe the process by which change within an organization will be achieved.

IDEF3 is useful in both capturing the system description and in model

development (Belhe and Kusiak 1995). A well developed description and conceptual

model will be very useful in the reuse of model components. Additionally, IDEF3 allows

for the capture of alternative views or descriptions enhancing the understanding of the

system and the usefulness of the model. Mayer et. al. explained,

> "When compared to model building, description capture is attractive as a strategy for knowledge acquisition for several reasons. First, practitioners generally require less training to produce descriptions, rather than models, of their domains. Second, a model description of a given situation can easily be reused for a variety of purposes, including model building (e.g., function models, simulation models). IDEF3 is a description organizing

and capture method that directly addresses these needs" (Mayer, Menzel et al. 1995).

IDEF3 Components/Elements

IDEF3 methodology has four major components. Boxes or UOBs are used for processes, arrows or links to represent precedence or relationship, junctions are used to add logic to the diagram, and circles are used when focusing on ontological descriptions to represent object states. Additional symbols include referents and notes. The IDEF3 schematic serves to detail the simulation concept. The mission space contains the process elements and is comprised mostly of the schematics. The simulation space and the simulation context are addressed by elaborations, notes, and referents that will be discussed later. The following figures provide an example of the two types of diagrams developed through the IDEF3 methodology.

Figure 7 provides a simple view of the process-oriented perspective. Within this diagram are several processes linked together showing the order of precedence. Although this diagram is simple in nature, it contains the all the key components of a IDEF3 schematic. Additional information and documentation can be added as necessary and will be discussed later in this chapter.
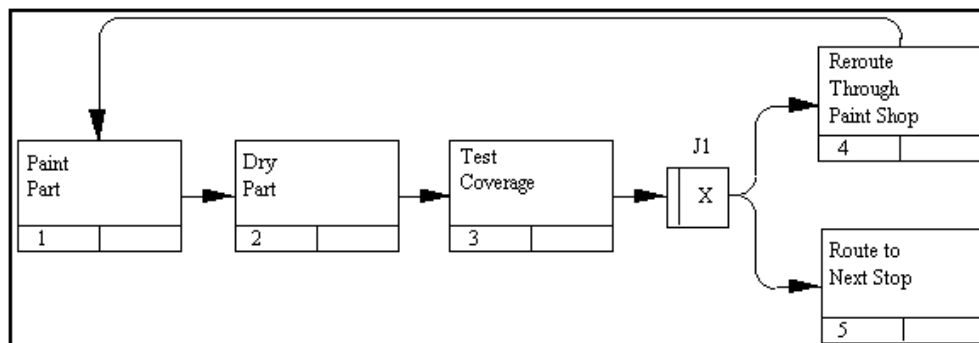
Figure 7. Sample IDEF3 Process Diagram

(Mayer, Menzel et al. 1995)

Figure 8 provides an example of how IDEF3 can be used to produce an object-oriented diagram. In this view, an object and its current physical state are represented by the circles with the processes acting upon the object coming in perpendicularly. This viewpoint can be used to follow and object through various processes detailing the current status of that object.
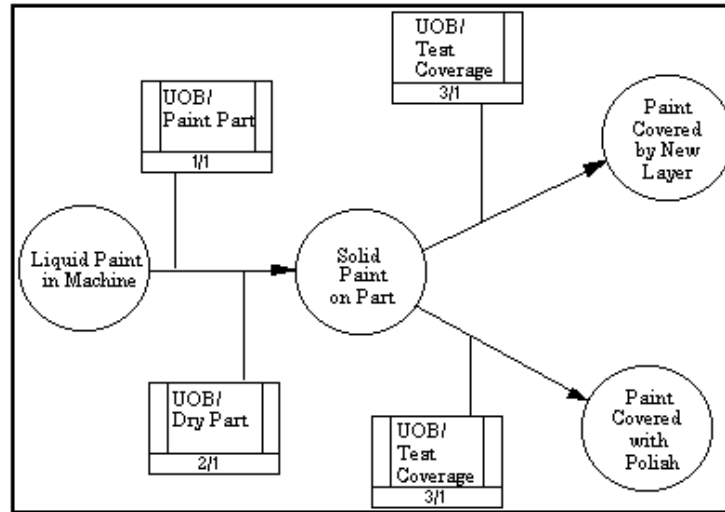
Figure 8. Sample IDEF3 State Diagram

(Mayer, Menzel et al. 1995)

Both the previous examples utilized the most common symbols; however, there are more symbols that help to make the IDEF3 methodology more useful. The basic elements used to develop an IDEF3 description are contained in Figure 9.

UOBs are used to describe what happens in general within the system and not necessarily what happened at a particular time. It represents an activity that happens repeatedly over time. In the case of a process, the description represents types of situations that can occur in the system and the logical and temporal constraints that bind them together (Mayer, Menzel et al. 1995).

Process Schematic Symbols	Object Schematic Symbols

UOB Symbols

UOB Labels

| Node Ref # | IDEF Ref # |

Object Symbols

Object State Label

Individual Symbols

Individual Label

Links

Simple Precedence Link

Constraint Precedence Link

Relational Link

Links

Weak Transition Link

Strong Transition Link

Relation Label — n - Place First-order Relation Symbol

Relation Label — 2 - Place Second-order Relation Symbol

Junctions

& – AND

O – OR

& – Synchronous AND

O – Synchronous OR

X – XOR

Junctions

& – AND

O – OR

X – XOR

Connecting Symbols

Referents and Notes

Call and Continue Referent

Referent Type/ Label
Locator

Call and Wait Referent

Referent Type/ Label
Locator

Note

Note ID

Figure 9. IDEF3 Methodology Schematic Symbols

(Mayer, Menzel et al. 1995)

Links are used to connect symbols creating the dynamic process representation.

Primarily used to denote relationships, links generally include express temporal, logical,

causal, natural, and conventional. The most common use is for temporal precedence

represented by a solid black line with an arrow point on one end. Additionally, there are

four types of constrained precedence links. They are represented by a directional triangle on the line, a double triangle allowing for both directions, and a square representing a general constraint. Lastly, dashed links are not predefined and are therefore usually user defined (Mayer, Menzel et al. 1995).

Junctions provide for the ability of expressing the logic of process branching while simplifying temporal sequencing relationships between processes. There are four types of junctions.

- Points at which a process diverges into multiple parallel subprocesses;
- Points at which a process diverges into multiple (possibly nonexclusive) alternative subprocesses;
- Points at which multiple parallel subprocesses converge into a single "thread;" and
- Points at which multiple alternative subprocesses in the process converge into a single thread.

The four types of junctions represent the four sorts of branch points. The first two represent the fan-out type while the remaining two are for fan-in type branches. Conjunctive branches are used with multiple parallel processes while disjunctive branches are used with multiple alternative subprocesses. Conjunctive branches are represented by the symbol "&." Disjunctive branches can be either inclusive or exclusive represented by "OR" and "XOR" respectively (Mayer, Menzel et al. 1995).

Table 4. IDEF3 Junction Types

Junction Type	Logic	Synchronization Type	Description
Fan-in	AND	Asynchronous	All preceding processes must be completed before preceding forward.
	OR		One or more of the preceding processes will complete.
	AND	Synchronous	All preceding processes will complete simultaneously.
	OR		One or more of the preceding processes will complete simultaneously.
	XOR		Exactly one of the preceding processes will complete.
Fan-out	AND	Asynchronous	All following process must start.
	OR		One or more of the following processes will start.
	AND	Synchronous	All following processes will start.
	OR		One or more of the following processes will start simultaneously.
	XOR		Exactly one of the following processes will start.

(adapted from (Vernadat 1996)

To further enhance the ability of the IDEF3 methodology for process description, decompositions are added to give greater detail and insight into the system. Decompositions are used to generate a hierarchical view of the process showing the subprocesses contained within a single UOB. By enabling this "drill-down" or exploded viewpoint capability, it is possible to view the process at various levels of detail depending on the information desired.

Additionally, various types of information can be attached to a process. This information includes elaborations, properties, simulation info, attachments, decompositions, notes, and sources. As they appear in ProSim 7.0 from KBSI, an Elaboration block is used to provide information about objects, facts, and constraints. The types of properties added are integer, real, string, Boolean, or user defined. With each property is stored its value, a description, notes, and source information. If needed, simulation data can be entered and stored. Attachments can be inserted to provide additional information including data files, pictures, or text. A list of decompositions and access to information regarding each is accessible at this point; each decomposition can contain any of the symbols available representing some subsystem within the whole process. Lastly, notes may be added to give further explanation and sources of information may be recorded to allow others to return to the source for further explanation.

Like the Elaboration block in a process diagram, there is an additional block in the object-centered view: Referent. Referents enhance understanding and simplify the construction of descriptions. Referents are generally used to accomplish three functions.

- Refer to a previously defined UOB without duplication of its definition to indicate that another instance of a previously defined UOB occurs at a specific point in the process (without loopback).

- Transfer control or indicate a loopback in the processing.

- Form references or links between the process schematics and object schematics.

There are two types of referents: Call-and-Continue Referent and Call-and-Wait Referent. The Call-and-Continue type is the most common used referent and represents a situation where the referenced element needs to be initiated and then the processes can

continue. The Call-and-Wait type represents the situation where situation where the

process continues after the referenced element has completed its processing. The

following table contains the various referent symbol structures.

Table 5: Referent Symbol Structure

Referent Type	Referenced Element Label	Locator
UOB	UOB Label	UOB#
SCENARIO	Scenario Label	Scenario #
TS	Transition Schematic Label	Transition Schematic #
GO-TO (used only in process schematics)	UOB Label	UOB#/Scenario # or Decomposition # in which the ID occurs
	Scenario Label	Scenario #
	Junction Type (i.e., &, O, or XOR)	Junction #/Scenario # or Decomposition # in which the ID occurs

(Mayer, Menzel et al. 1995)

IDEF3 Development
Cochran and Wheaton suggest that development of a IDEF3 model begin with a

simple context model, be supplemented with an activity model containing discrete

elements, and then add a hierarchical breakdown view of activities (Cochran and

Wheaton 2002). When developing IDEF3 descriptions, the following evolutionary cycle

can be used to capture the knowledge about activities and processes.

- Collect: Acquire observations and written descriptions of both process instantiations and generalizations across process instantiations.

- Classify: Individuate situation types, objects, object types, object states, and relations.

- Organize: Assemble the data that has been collected and classified using IDEF3 structures

- Validate: Ensure that the statements made in IDEF3 are grammatically correct and that they corroborate with the collected descriptions of the actual or idealized situation.

- Refine: Make adjustments to the existing structures to incorporate newly discovered information, to simplify the presentation, or to highlight important elements interest (Mayer, Menzel et al. 1995).

Using these steps and a combination of the conceptual model building steps suggested by Benjamin et al and Pace should enable the model developer to gain a greater understanding of the process while providing the appropriate amount of detail needed for reuse and conversion to a simulation model.

Conclusion

For this research effort, data concerning the processes surrounding space shuttle ground turnaround operations will be collected and used to generate UOBs with elaborations and other descriptions being generated as needed. The data will come from work breakdown structures, process diagrams, tables and spreadsheets, and from subject matter experts. The data will be organized as needed and then organized into an IDEF3 structure that will paint the picture of operations at KSC. Once the IDEF3 model has been generated, the researchers will validate the model based on the data collected and descriptions generated ensuring statements made are grammatically correct and that they express the proper view of the actual system. If any new information is uncovered during this process, it will be added and adjustments will be made while the model is kept as simple as needed and contains enough detail to be complete.

Five steps will be used to conduct the data analysis. The first is to organize the data and facts. This is a general collection and organization. The next step is to identify

categories for organizing data and facts into meaningful groups. The third step is to give special attention to specific items requiring examination for relevance. Next, patterns and groups are determined based on a logical structure for the model. The last step is to proceed with model development (Leedy and Ormrod 2000).

To simplify the model development process and to enable the completion of the above steps, a simple method has been chosen to reduce the data to a more manageable and meaningful level. Data relating to procedures scheduled and performed on the space shuttle on a regular basis will be included. Data such as trouble shooting unexpected errors or malfunctions and modifications will be removed from the data set. Any subsequent data generated as a result of these procedures will be removed as well. Chapter 4 will detail this process and how it was conducted with the actual data as well as present the various components of the model.

To build the model, the system will need to be divided into usable and meaningful groups. Several possibilities exist for these groupings. First, all the processes within each structure could be grouped and modeled. Another possible method would be to group by similar structure or function—component based. In this model, the grouping would be by system or sub-system regardless of facility. Additionally, the groupings could be based on process ID or procedure number. This would allow similar activities to be grouped. However, each of these on their own would not provide a proper description or dividing point for data analysis. The best choice is a combination of the three. In general, activities will be grouped by system or sub-system with procedure numbers and process IDs being used to help make this division. In some cases, the

procedures for a single system occur in multiple facilities; therefore, larger more complex procedures will be first divided by system and then subdivided by facility.

By focusing on systems rather than some other grouping method, the focus is placed on the entities where trade-offs will occur. Also, the model will be more adaptable and attuned towards reuse. As changes are needed for each sub component of the model, only that section will require action. Additionally, components of the model will be ready for inclusion or exclusion as required in order for the model to evaluate various scenarios.

In the end, the IDEF3 model will provide the necessary data for the simulation developers to understand the processes involved in space shuttle turnaround enabling them to analyze the system further for the development of a generalized simulation. Based on this initial understanding, the simulation developer will be able to prepare for various alternative choices and analyses needed to aid in system development. One of the main advantages to be gained from this effort is an understanding of process flow, precedence, and relationships in the form of IDEF3 schematics with drill down capability on processes that require greater detail.

IV. Analysis and Results

Overview

This chapter will answer Investigative Question # 4 utilizing the methodology discussed in Chapter 3 (Question # 3). This chapter will begin with the scope and limitations of this analysis will be discussed followed by the threats to validity. The assumptions made in laying out the conceptual model will be discussed in addition to the analysis of the data followed by the results. The results will be in the form of a more detailed discussion of the operations at KSC as laid out in the model along with appropriate diagrams with the full model being included in Appendix B.

Scope and limitations

The scope of this project was to stay within the Domain Analysis function and was therefore limited to the development of a conceptual model. The analysis and subsequent model development will be limited by the data available from KSC. The model developed will be a baseline conceptual model; no analysis of the processes will be made.

Threats to validity

Researcher bias may influence data examined either by preconceived ideas on process flow or by leaving out data that was felt to be unimportant. When collecting data from an individual, the interviewee may influence the analysis by answering questions based on their own opinion of the data and/or by selectively or inadvertently supplying or not supplying data. The data collected is primarily dependent upon the resources

available at KSC. If the data is not available or lacking, the model will either be

inaccurate or insufficient in the area of concern. Additionally, the sponsor may influence

the direction of research effort based upon their own preconceived ideas.

Assumptions

The selected assumptions may influence data examined, responses from the interviewee,

interpretation of observed operations, and data selection. Selection of model components

may affect the usefulness and generalizability of the model. The following assumptions

were used when analyzing the data and building the model:

- Unscheduled maintenance and troubleshooting is not relevant to the development

  of this baseline model. This data represents activities not performed on a regular

  basis.

Data analysis

The basis for the data analysis is a contextual analysis. The data was examined

for activities that represented the general flow of operations at KSC for the turnaround of

the space shuttle and its components in preparation for the next launch. These operations

included those for processing the orbiter and its major subsystems, the solid rocket

boosters (SRB), the external tank (ET), and the mobile launch pad (MLP). The

processing of the orbiter comprises the greatest amount of time and effort. Because of its

size, this activity required decomposition for greater analysis and understanding.

The breakdown of orbiter processing was driven by its size and complexity and

one additional factor: reusability. In order for this model to be useful in examining other

vehicles and conducting trade-off analysis when coded as a simulation, the data was

divided into groups allowing for the creation of modules. These modules could then be

included or excluded as necessary for varying vehicle types. For example, a new type of

TPS might be developed that does not require the use of tiles. Therefore, the tile

manufacturing module would no longer be necessary.

To analyze the data, a three step process was used modeled after the first four of

Leedy's five steps in Chapter 3. The first step was to organize and collect the data. Next,

areas requiring special attention for examination need to be identified examining the data

for relevance. The third step is to group the data into categories looking for patterns and

logical structure.

Organize and collect the data
The data used in this analysis came from several sources and in several different

formats. The formats of the data were as follows:

- Spreadsheets

- Tables

- Flowcharts

- Gantt Charts

- Presentations

- Pictures

- Diagrams

- Reports (textual)

This data provided names of various processes and subprocesses in addition to start and

stop times. It provided descriptions of flows and sample high level diagrams that were in

some cases the only source of data for analysis. Also, there were pictures and

descriptions of facilities. Some sources provided detailed descriptions of various systems

and components. Other sources provided high level scheduling data while others

provided detailed processing data down to the individual task performed.

Some of the data was focused on Space Transportation System (STS)-81, which is

considered the baseline minimum scheduled time. Other data sources were from

combined mission data for post-Challenger missions. The pre-challenger missions were

considered to be too dissimilar to those following that they were not included.

Additionally, STS-114 was included at a higher level of detail as a comparison to STS-81

along with a generalized schedule.

Identify categories
What was discovered is that the same general procedures are completed on each

mission especially those concerning major systems that are of greatest interest. The

differing data sources provided varying levels of detail from system to system, but when

combined provided a clearer picture of procedures throughout the whole ground

turnaround process. Some influence in this matter came from the sponsor's focus on TPS

and propulsion systems.

The area containing the greatest amount of information was the data sources

concerning the space shuttle main engines (SSME) and the thermal protection system

(TPS). These two areas are considered the most important for trade-off analysis and have

been the focus by both NASA and AFRL/VA. Therefore, the initial emphasis was placed

on these two systems. Other areas were added as data and time permitted with the intent

of producing the most comprehensive and complete model possible.

Group the data
When examining the data, some sources contained extraneous data needing to be

filtered out to enable a clearer view of the pertinent data. Some of this data concerned

non-maintenance activities and were thus not part of the ground operations; some of the data was for operations not performed at KSC; and some concerned unscheduled maintenance. Additionally, data concerning modifications and upgrades was not included in the model. Any data not scheduled or out of the scope of this research was removed from the data set and was not considered in this effort.

Results: Baseline Conceptual Model

This section will detail the model as developed beginning with the highest level and then presenting each decomposition as necessary to clarify the major components of the model. Diagrams from the model will be provided as needed while the whole model will be available in Appendix B.

Overarching
KSC is responsible for launch operations, landing and recovery procedures, and ground turnaround for all equatorial orbits. The ground operations at KSC required to turnaround the space shuttle being considered are those from launch to launch but not including any mission elements. Launch to launch is considered since some of the activities considered begin soon after launch—such as SRB retrieval and MLP refurbishment, which begin soon after launch. The major activities take place in several different facilities located relatively close to each other with the exception of hazardous functions being geographically separate.

The shuttle industrial complex is composed of many buildings utilized in the processing of STS components and systems. Some of the facilities are left over from the APOLLO space program and some are new structures built specifically for the shuttle

program. Additionally, there are facilities in other areas that support the shuttle mission.

The facilities considered in this effort are the hypergol maintenance and checkout facility

(HMF), TPS facility, OPF, vehicle assembly building (VAB), MLP refurbishment

facility, and launch pad. Within some of these facilities may exist multiple structures and

bays. The details of these facilities will be discussed along with the operations are

conducted within that facility. Figure 10 provides the schematic for this schematic.
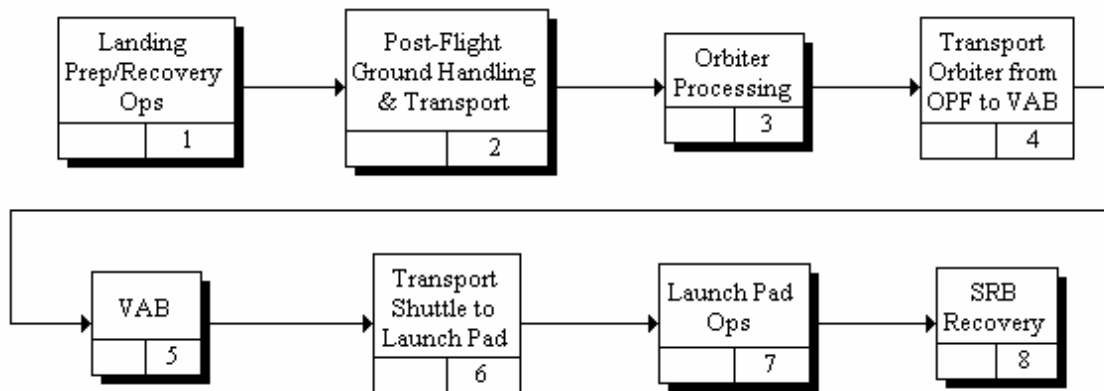

Figure 10. Overarching Diagram

1.0 Landing Prep/Recovery Operations
This module discusses the operations conducted beginning when the landing is in

preparation and when the orbiter actually touches down. Prior to landing, vehicles,

equipment, and personnel are made ready. Additionally, the weather is checked to ensure

all things are go for a landing at KSC. NASA does have three other locations for landing

if the weather is not good at KSC and time is short (not modeled in this effort). Once the

decision is made to land at KSC, vehicles, equipment, and personnel take their positions

and converge on the orbiter once it comes to a stop. Before the crew may exit the orbiter

and maintenance personnel may approach, a toxic vapor test is conducted. Once the area is declared safe, the crew exits, time critical payloads are removed, some systems are purged, a walk down inspection of the TPS is made, and the tires are inspected. Figure 11 provides the schematic for this decomposition.
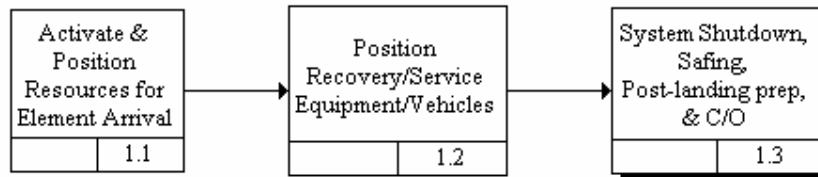

Figure 11. Landing Prep/Recovery Operations

2.0 Post Flight Ground Handling
This module concerns the operations necessary to transport the orbiter from the runway to the OPF. Once on the ground the orbiter has no means of propelling itself; the orbiter free falls and then glides to a landing having no powered flight on re-entry. When ready, the orbiter is then towed to the OPF for processing.
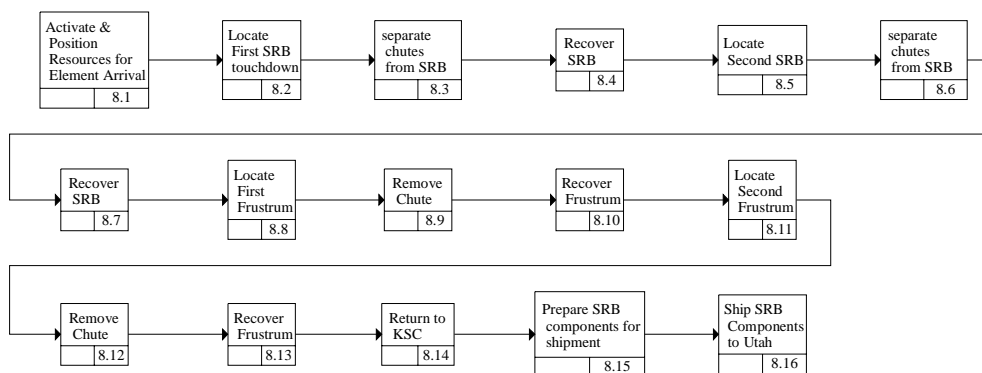

Figure 12. Post Flight Ground Handling

3.0 Orbiter Processing

This is the single largest module containing several decompositions with some having multiple decompositions of their own. The dividing of data and creation of modules for the model was in part driven by divisions present in the data form KSC. KSC tended to look at systems and divide the actions on those systems by facility. Therefore, this research effort took advantage of the inherent divisions within the data.

Before diving into the model, a brief overview of the major facilities involved with this section is required. A description of the OPF and the HMF will be provided followed by a description of the orbiter processing decomposition. Figure 12 provides the schematic for this level of decomposition.

OPF

Within the OPF are three bays. Since there are three orbiters in the inventory, physical capacity is not a problem. Operations considered for the OPF are those that begin at OPF roll-in and end at rollout but do not include concurrent operations in other facilities. For example, the SSME are removed and sent to the orbiter main engine maintenance facility (OMEMF) and are either returned or replaced with already refurbished engines. The operations in the OMEMF will be dealt with separately. The main activities in the OPF considered for modeling by NASA have been broken down to three areas.

- External surface preparation to include the TPS.

- Payload, midbody, and crew compartment work.

- Propulsion system especially around the main engine compartment.

Not mentioned above are many other important tasks that must be integrated into the flow such as: safing the forward reaction control system (FRCS), changing the tires; polishing the windows; trouble-shooting the previous

mission's in-flight problems and a host of minor problems that occur during the course of any OPF flow; and performing approved modifications (Cates 2003)

For the OPF, the orbiter is rolled in, jacked up, and remains in place until it is time to lower it down and send it to the VAB. Personnel, tools, and test equipment come to the orbiter. Some components are removed and maintenance is performed in other locations. When servicing is complete, those components are returned and reinstalled. OPF processing takes approximately 80 days to complete.

HMF
The HMF is one facility where components may be removed and taken to for further maintenance and is located approximately 8 miles from the main complex due to hazardous materials (hypergolic fuels) handling. This facility is used to process reaction control system (RCS) components, orbital maneuvering system (OMS) pods, and auxiliary power units (APU). The HMF consists of three buildings which contain test cells for the OMS pods and FRCS, storage for the OMS pods and FRCS, and maintenance/servicing centers for the APUs. Building M7-961 contains two test cells each one for either the left or the right OMS pod. Building M7-1212 contains two bays as well. One bay is for FRCS processing and the other is not functional. The latter bay is used for storing one OMS pod or one FRCS.
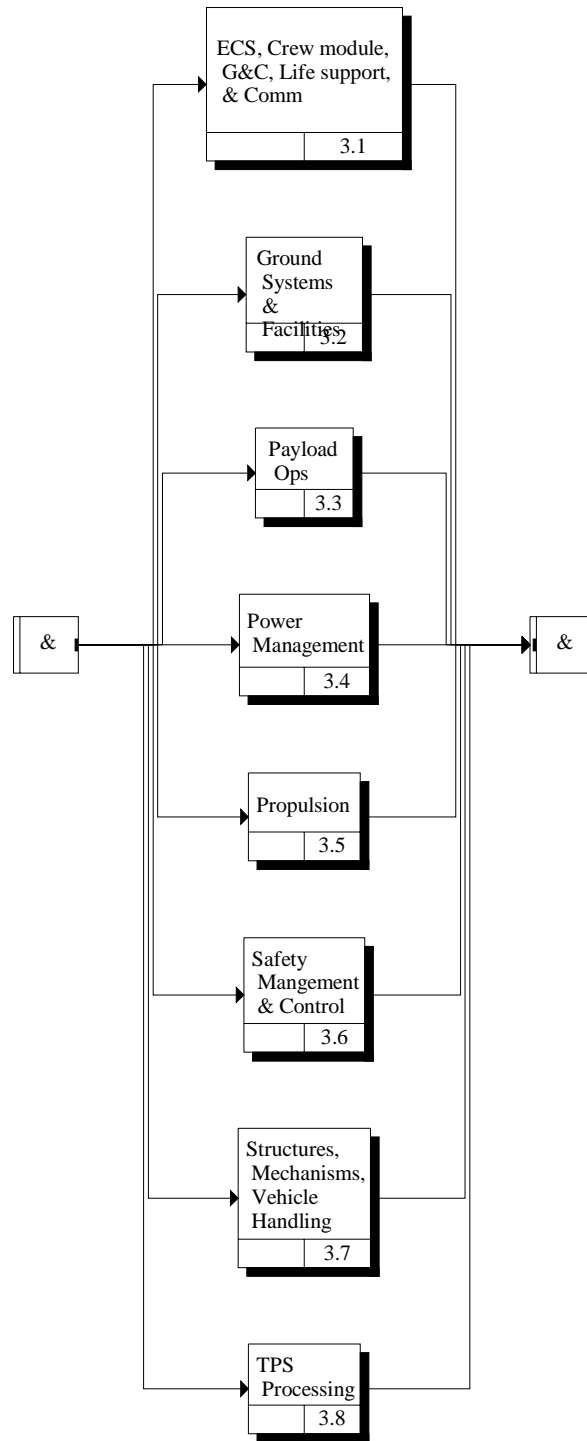
Figure 13. Orbiter Processing

3.1 ECS, Crew Module, GNC, Life Support, & Comm

Development of the ECS, Crew, GNC, Life support & Comm module was based

upon data documented in the OPF_dB_STS81_LbrClrs excel spreadsheet. The initial

239 lines of data were initially reduced by approximately thirty percent by removing lines

of data designated as "unplanned troubleshooting and repair". The remaining 167 lines

of data were broken down by five "design disciples" for model development including:

- Command, Control, & Health Management

- Guidance, Navigation and Control (GNC)

- Cockpit & Crew Panel

- Environmental Control & Life Support System (ECLSS)

- Communications (COMM)

Though start and finish data was provided, it was unclear if this resulted from a physical

or resource constraint. Therefore, unless obvious precedence was observed (i.e., removal

before installation), tasks are modeled in parallel.

Command, Control, & Health Management subsystem includes the computer

processors (DPS) and multifunction electronic display (MEDS) as well as orbiter

instrumentation. The GNC system utilizes the four of the DPS computers during critical

flight control phases of the mission. Recycling tasks within these modules are non-

hazardous in nature and include checkouts of the DPS complex, MEDS, flight recorder,

master timing unit, and other instrumentation systems.

Cockpit & Crew Panel and the ECLSS include inspection and maintenance of the

cabin air conditioning/recirculation and flight-crew systems. The ECLSS system is

critical to the atmospheric conditions within the crew station. Of primary importance is

the control of temperature and pressures required not only for survival of the crew, but also critical electronics. Tasks within this module are non-hazardous and the inspection and maintenance of the cabin air recirculation system require orbiter power down conditions.

The communication system includes the microwave scanning beam landing system, the KU band antenna (located in the payload bay), the tactical air command & navigation system, GPS antenna, close circuit television, among other systems. Inspection and testing tasks within this module are non-hazardous.
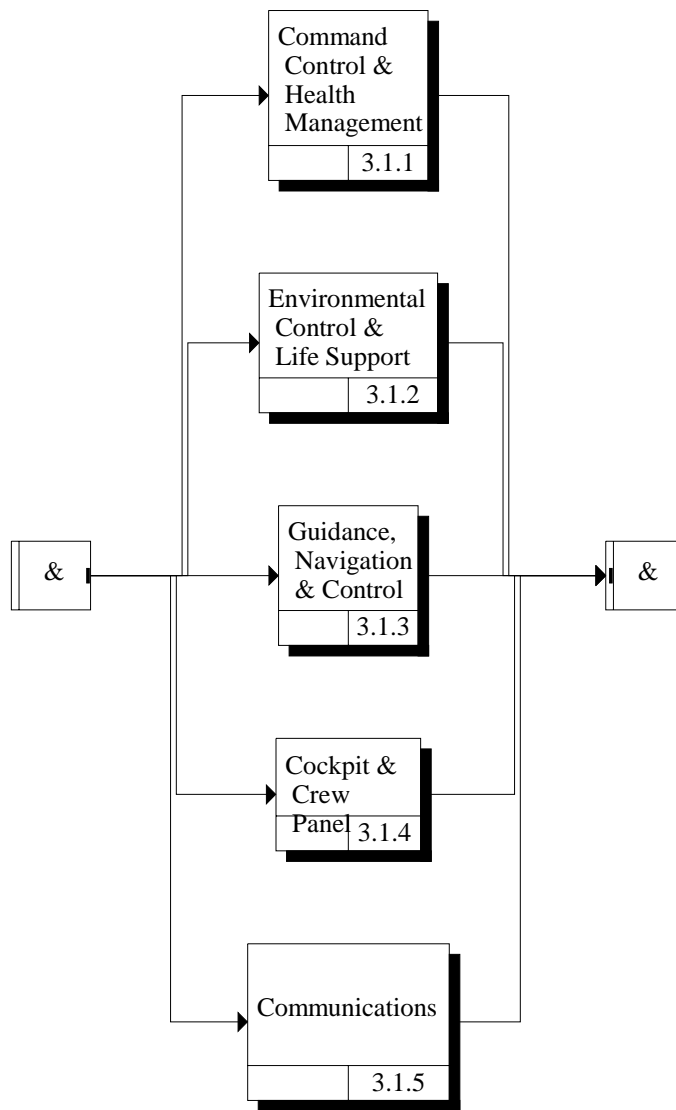
Figure 14. ECS, Crew Module, GNC, Life Support, & Comm

3.2 Ground Systems and Facilities

Within this module, the orbiter is connected to various ground systems providing

power, cooling, and other services shutdown when the internal systems were deactivated.

In addition, the orbiter is jacked up off its landing gear and suspend. Next, ground access

systems are put into place allowing access to all parts of the orbiter from top to bottom.

These systems can be moved and adjusted to gain access to various parts of the orbiter
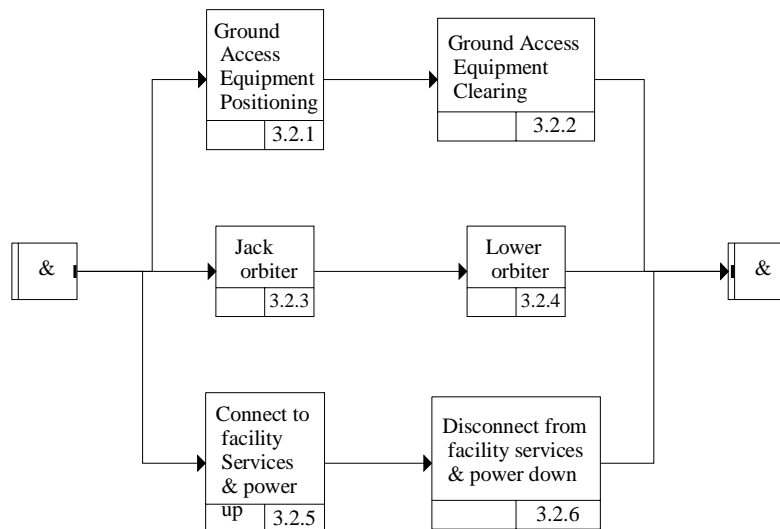
without obstructing other procedures.

Figure 14. Ground Systems and Facilities

3.3 Payload Ops
Though data was available in the OPF_dB_STS81_LbrClrs excel spreadsheet, it

was unclear which data was generic payload bay preparations versus specific mission

payload tasks. As a result, development of the Payload Accommodations module was

based upon data documented in the STS-81/OV-104 OPF Assembly Summary Gantt

charts. Though start and finish data was provided, it was unclear if this resulted from a

physical or resource constraints. Therefore, unless obvious precedence is observed or

milestones provided, tasks were modeled in parallel.

The payload bay area contains four critical systems; orbital docking system, radiator system, and fuels cells, and the crew equipment interface system. The conceptual model initiates parallel functional/mechanical testing verification, and closeout of these systems. Following closeout of the individual systems, the payload bay undergoes a final cleaning, closeout and the function of hatch is verified.
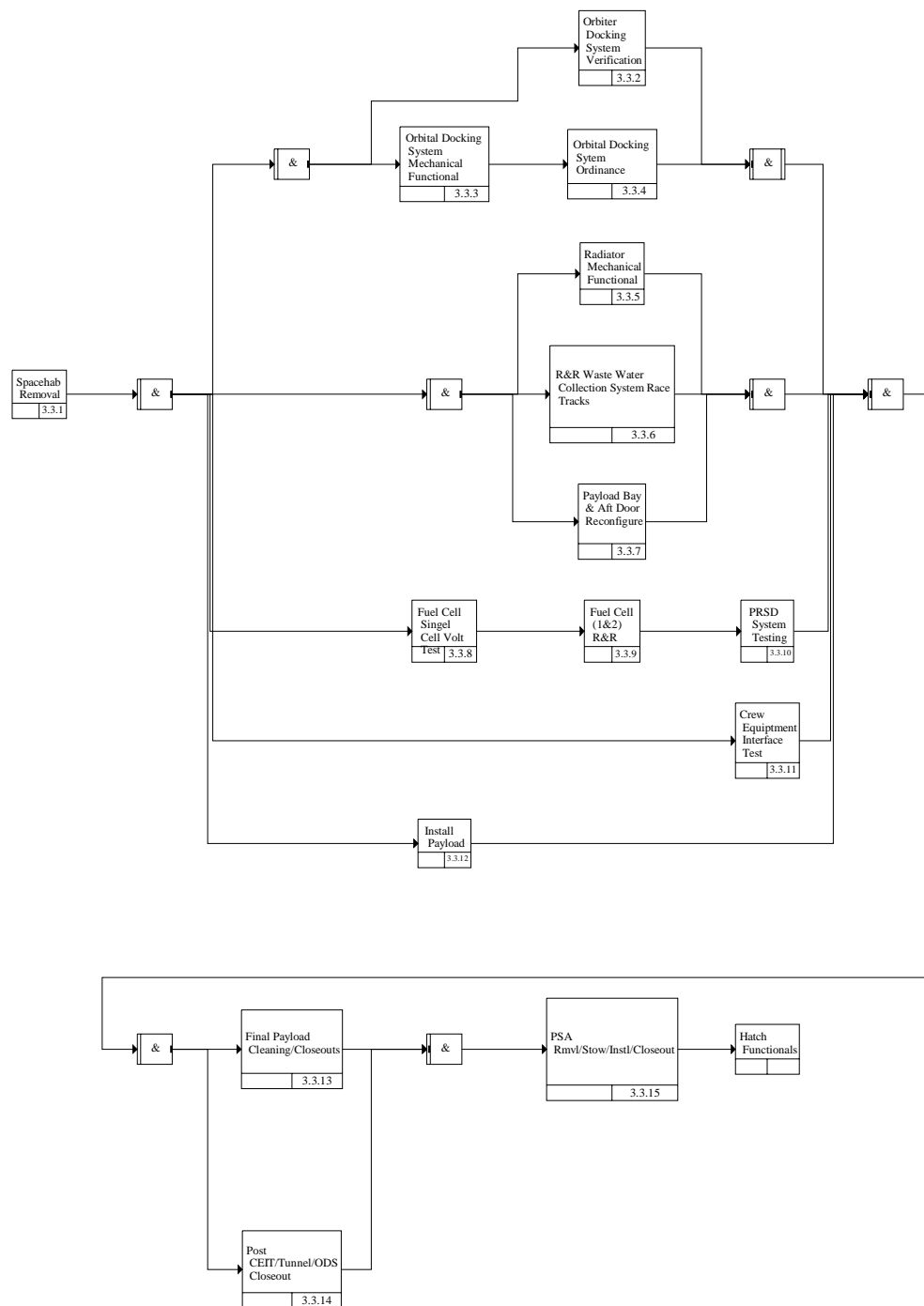
Figure 15. Payload Accommodations

3.4 Power Management

Development of the Power Management module was based upon data documented in the OPF_dB_STS81_LbrClrs excel spreadsheet. The initial 324 lines of data were initially reduced by approximately forty-two percent by removing lines of data designated as "unplanned troubleshooting and repair". The remaining 187 lines of data were broken down by six subsystems for model development including:

- APU

- Electric Power Distribution

- Fuel Cell Systems (FCP)

- Hydraulic Systems

- Orbiter Electrical

- Orbiter Test Conductor Operations

Though start and finish data was provided, it was unclear if this resulted from a physical or resource constraint. Therefore, unless obvious precedence is observed, tasks were modeled in parallel.

The APU is a hydrazine fueled system that provides pressure for the hydraulic system. Hydrazine, a toxic liquid, requires special handling during the recycling process. Toxic vapor checks are required to determine if repair is required. This system is inspected at the OPF; however, the repair is accomplished at the HMF. Following repair, the APU system is returned to the OPF for installation and leak functional testing.

The FCP system generates power for the orbital electrical system. The activities within this part of the module include testing the power reactant storage and distribution

system (stores and distributes oxygen & hydrogen reactants to fuel cells) and servicing of the waste spray boiler (WSB) used to cool the APU system.

The recycling of the hydraulic systems begins with the inspection of the hydraulic system, including the checkout and servicing of the WSB used to cool the hydraulic system. Following servicing of the hydraulic system, the system is powered up for the functional checkout of the circulation pumps, flight control system, SSME, OMS, nose landing gear, and hydraulic brake systems.
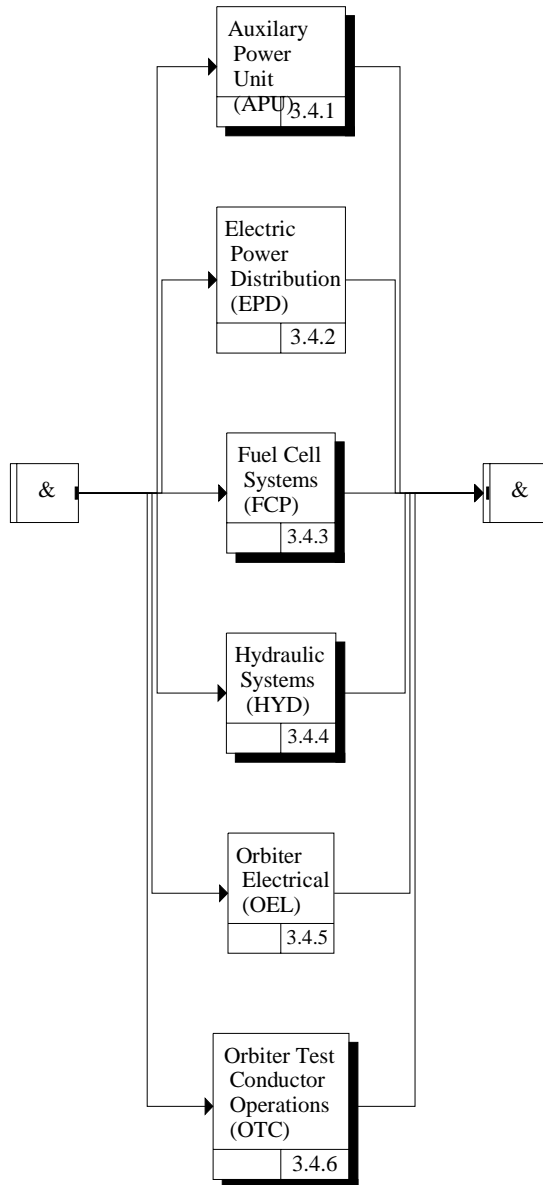
Figure 15. Power Management

3.5 Propulsion

Development of the Propulsion module was based primarily upon data documented in the

OPF_dB_STS81_LbrClrs excel spreadsheet. The initial 230 lines of data were initially

reduced by approximately thirty-three percent by removing lines of data designated as

"unplanned troubleshooting and repair." The remaining 165 lines of data were broken

down by five subsystems for model development including:

- Shuttle Main Engines (SME)

- Ground Support Equipment

- OMS

- Main Propulsion System (MPS)

- Nondestructive Evaluation

Though start and finish data was provided, it was unclear if this resulted from a physical

or resource constraint. Therefore, unless obvious precedence is observed, tasks were

modeled in parallel. The exception to this analysis methodology was the SME module

which was based upon the data provided in a NASA Report (Christenson & Komar 1998:

50-59). Data provided in this report included not only start and finish data, but also

precedences. The SME must be removed, inspected, and repaired between each flight.

Therefore, the conceptual model propulsion model is broke into three sections; activities

that occur from OPF roll-in to SME removal, engine repair, and SME installation to OPF

roll-out.

Following OPF roll-in, the SME is dried and inspected, the heat shield removed,

and the low pressure pump torque is checked. The MPS lines are checked, protective

covers installed, leak and function tests are performed. The OMS subsystem is safed,

deserviced, and inspected. Approximately 12% of these inspections result in a need for

repair/servicing of the OMS pods. Similarly, 38% of these inspections result in a need

for repair/serving of the FRCS. The repair of the OMS and FRCS is hazardous,

therefore, if the OMS and FRCS require repair, they are sent to HMF.

Once the SSMEs are removed, they are taken to the OMEMF and serviced.

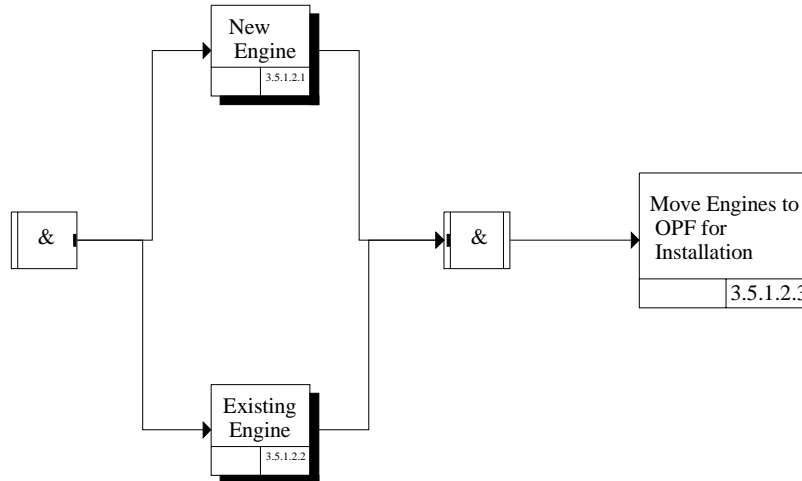Figure 16 provides the flow at this level.

Figure 16. OMEMF

In the event that a new engine would be used, the process flow would be quite

different much simpler than that of the existing engines. Figure 17 provides the
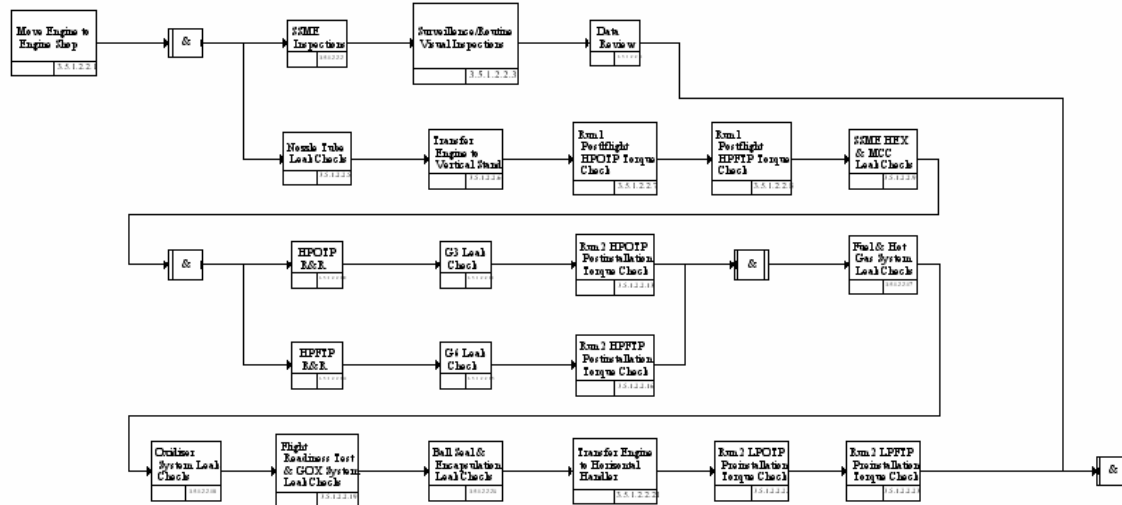
schematic for this level of decomposition.

Figure 17. Existing Engine

When a replacement engine enters the OPF, it is inspected prior to installation.
The engine is installed and integrated with the MPS. SME/MPS integration is tested, the
engine and dome mounted heat shields are installed, the gimbal clearance is checked, and
the SME inspected prior to OPF roll-out.

3.6 Safety Management and Control

Development of the Safety Management & Control module was based primarily
upon data documented in the OPF_dB_STS81_LbrClrs excel spreadsheet. The sole
subsystem in this "design discipline" is the Purge, Vent, and Duct system. This system
supports systems within unpressurized compartments by:

- gas purge for thermal conditioning

- prevent accumulation of hazardous gases

- provide venting during ascent and reentry,

- drain trapped fluids,

- condition window cavities to maintain visibility.

3.7 Structures, Mechanisms, and Vehicle Handling

Development of the Structures, Mechanisms, and Vehicle Handling module was based

upon data documented in the OPF_dB_STS81_LbrClrs excel spreadsheet. The initial

405 lines of data were initially reduced by approximately twenty-four percent by

removing lines of data designated as "unplanned troubleshooting and repair". The

remaining 309 lines of data were broken down by nine subsystems for model

development including:

- Ground Support Equipment

- Mechanism

- Nondestructive Evaluation

- Orbiter Handling Equipment

- Forward Panel Repair

- Pyrotechnic Systems

- Quality Engineering

- Orbiter Structures

- VPL

Though start and finish data was provided, it was unclear if this resulted from a

physical or resource constraint. Therefore, unless obvious precedence is observed, tasks

were modeled in parallel.

The Mechanism subsystem includes such systems as the orbiter docking system,

main landing gear assembly, nose landing gear assembly, and external tank door

operations. Each of these systems are inspected, and checked for leaks and function.

For example, the orbiter docking system was initially designed to dock with the Russian

Mir space station, but is now used to dock with the International Space Station. The

recycling process requires an inspection of the vestibule and an internal/external post flight inspection. If all is in working condition, a protective cover is installed and the docking mechanism undergoes a functional check.

The structure of the orbiter is also inspected, repaired, and checked out as part of the recycling process. Of interest in this area are the windows which must be inspected, polished, and sometimes removed and repaired. A vast majority of the "unplanned troubleshooting and repair" noted above is to the structure of the orbiter.
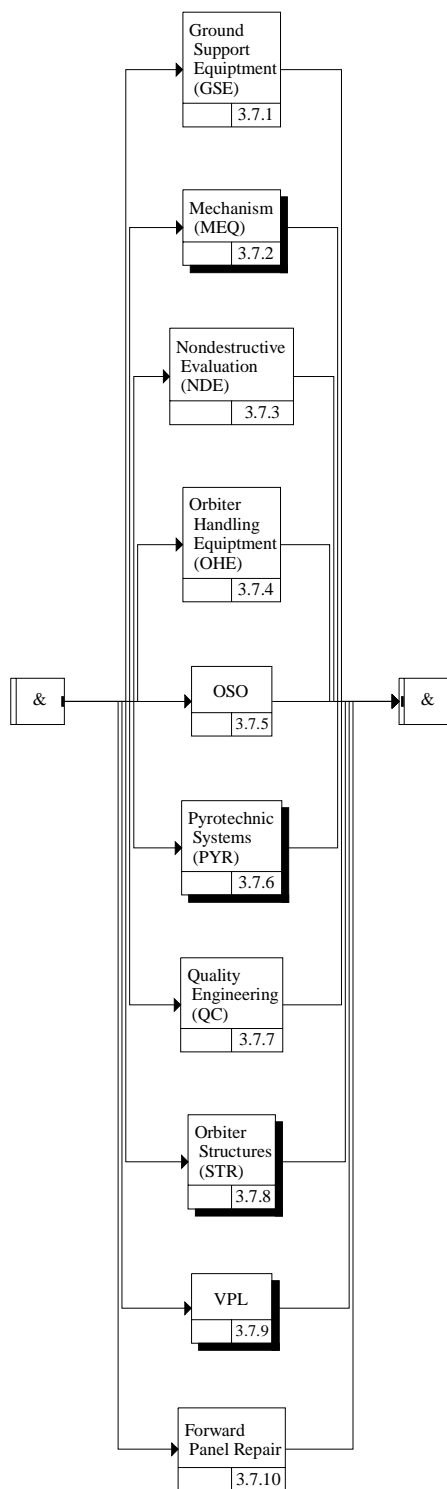
Figure 18. Structures, Mechanisms, and Vehicle Handling

3.8 TPS Processing

There are several forms of thermal protection on the orbiter. These items are either stored after delivery or manufactured at KSC. The most time consuming part of the TPS is the orbiter tiles, which are manufactured individually by hand or by machine. Each tile has a specific place on the orbiter and is not interchangeable. Servicing the TPS on the orbiter begins with a walk down inspection on the runway after landing. Once the orbiter is in the OPF, the inspection of the TPS begins and is broken into various hard to define groups. The inspection and maintenance of TPS components is an ongoing process throughout much of the OPF processing time. Therefore, the TPS procedures were not modeled moment by moment but rather by procedure beginning with the inspections.

There are eight components that make up the TPS each having subcomponents with various levels of inspection required. The main components of the TPS are as follows:

- Reusable Surface Insulation (RSI) Tiles

- Advanced Flexible Reusable Surface Insulation (AFRSI) Blankets

- Felt Reusable Surface Insulation (FRSI)

- Reinforced Carbon-Carbon (RCC)

- Gap Fillers

- Thermal Barriers

- Thermal Seals

- Window Thermal Panes

Depending on the location on the orbiter and the type of material, the item will either receive a macro-level or micro-level inspection. The macro-level inspection is

accomplished at a distance of 3 to 5 feet and is a visual inspection looking for major

inspections. In some cases, the macro-level inspection is a precursor to a more detailed

micro-level inspection possibly requiring specialized equipment and is primarily a hands-

on inspection. These inspections are further divided by 10 areas on the orbiter. For this

model, it was decided to group the inspections by these 10 areas when modeling the

inspections. Since the inspections can occur in any order and maintenance may begin

before all the inspections are complete, the model allows for the inspections and

maintenance activities to be performed in parallel as seen in Figure 19.
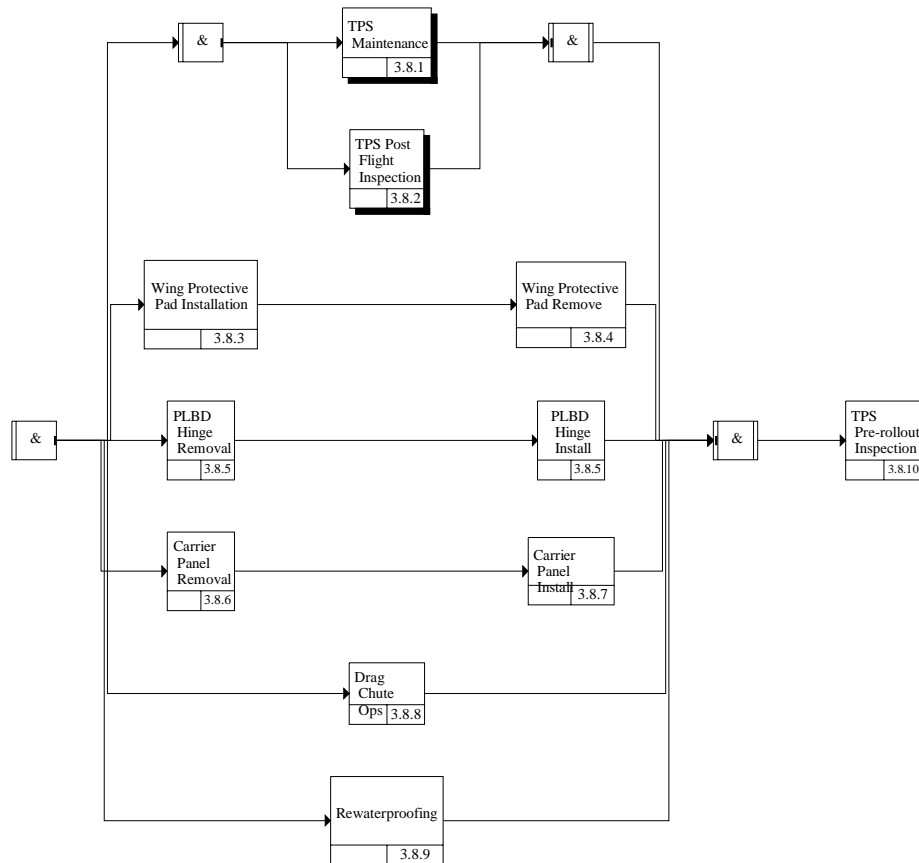

Figure 19. TPS Processing

Within the data concerning TPS maintenance falls the reworking of payload bay

door (PLBD) hinges and the orbiter drag chute used during landing to help slow the

orbiter down so the breaks may be used. During various operations, it may be necessary

to install protective pads on the wings of the orbiter so this task is modeled in parallel to

the inspection and maintenance activities allowing for the operation to occur as needed.

Additionally, the RSI tiles and FRSI must be rewaterproofed before each launch. The

waterproofing process makes the components hygrophobic (Gordon 1995). This process

keeps the components from taking on water and increasing weight and reduces the

possibility of damage. Since the waterproofing compound is hazardous, the

waterproofing operations are generally conducted on the third shift when no one else is

present. Those performing the waterproofing operations must where protective suits.

Much of the TPS is manufactured or assembled on site at KSC within the TPS

Facility. The components with more detailed operations were modeled with more detail

while others were included with only a description rather than a full decomposition. The

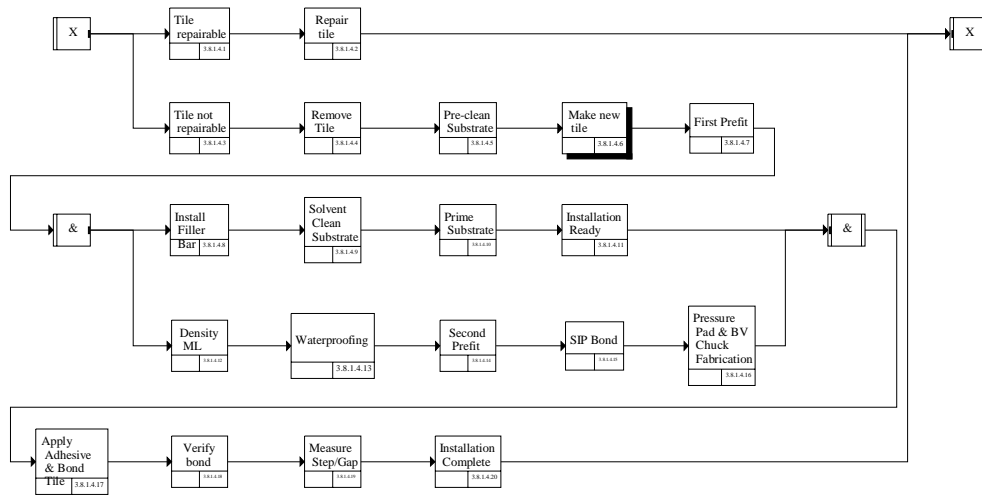most detailed operation is for the RSI tiles as seen in Figure 20.

Figure 20. RSI Tile Maintenance

The orbiter contains almost 20,000 RSI tiles of which 96 on average require replacement and 1,800 require repair. Tile replacement requires the greatest amount of time for TPS maintenance taking up to 60% of the total TPS man-hours. Inspections require 10% of the time, gap filler maintenance uses 22% of the time, and the rest is divided among the other components (Livingston and Rooney 2003). A major process that eats up much of the tile replacement time is tile manufacturing. It is clear that any new system using a different TPS system could potentially reduce processing time considerably.

Each tile is unique and requires machining form a tile blank that is produced on site at KSC. The tile can be made form a computer file or from a physical mockup made from the space it was removed from. In some cases, the physical model is digitized and manufactured on a numerically controlled machine the same as those using a computer file. Although the model allows for rework after pre-fit, the tiles made by hand require

more time and generate more rework and scrap which is not detailed in the model. Each

of the two pre-fits is conducted by taking the tile to the OPF and fitting it on the orbiter.

As a result of the pre-fit procedures, the TPS Facility is located near the OPF to help

reduce the time needed for tile replacement. Figure 21 contains the decomposition for
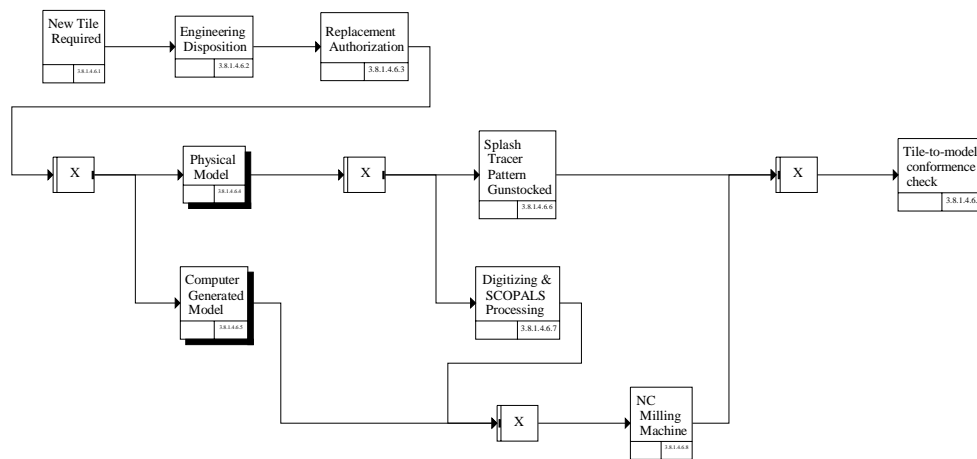
RSI Tile manufacturing.

Figure 21. RSI Tile Manufacturing

4.0 Transport Orbiter from OPF to VAB

After OPF processing is complete and post inspections are good, the orbiter is

transferred to the VAB. To transfer the orbiter to the VAB, the Orbiter Transport System

is used rather than towing the orbiter on its wheels; the orbiter's landing gear is closed

and sealed until extended for landing. The transportation process takes approximately 1

day to complete.

5.0 VAB

The VAB is where the SRBs are assembled, the ET is stored and processed, and

the shuttle components are mated to each other on top of the MLP. The VAB was

originally built to support the Saturn V rocket and is thus a very large facility with four

bays. Two bays are used for mating operations the other two contain one storage and one

checkout cell each for ET processing. Additionally, one of the latter bays may be used

for temporary protection of the shuttle assembly from inclement weather—such as a

hurricane. The VAB is designed to withstand winds up to 125 MPH.

The mating process generally involves the MLP being placed in one of two bays.

Then the SRBs are attached to the MLP. Next, the ET is mated to the SRBs but not to the

MLP; the SRBs will be the only objects mated to the MLP and will support all the

weight. The last major operation is the mating of the orbiter. This procedure is quite

delicate since the facility was not designed for this operation. The overhead crane system

is used to lift the orbiter and pass it at just the right angle through several support

structures until it is in the appropriate bay. Then the orbiter is put into its place. The

mating of all components takes approximately 1 week to complete. Other operations in

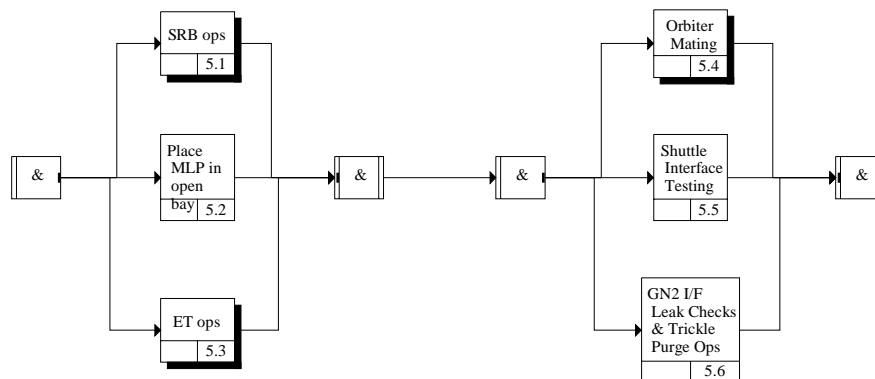the VAB surround the processing of SRBs and ETs.

Figure 22. VAB

Although final SRB assembly occurs in the VAB, most of the SRB operations occur in the nearby Rotation, Processing, and Surge Facility (RPSF). The RPSF contains three structures: processing facility, support building, and storage building. The processing building is used for receiving, inspecting, segment rotation, and aft booster buildup. The storage building can store up to eight segments or two boosters. The operations within the RPSF are considered hazardous since the boosters contain live solid rocket fuel. When the segments are ready, they are transported to the VAB for stacking as previously described.
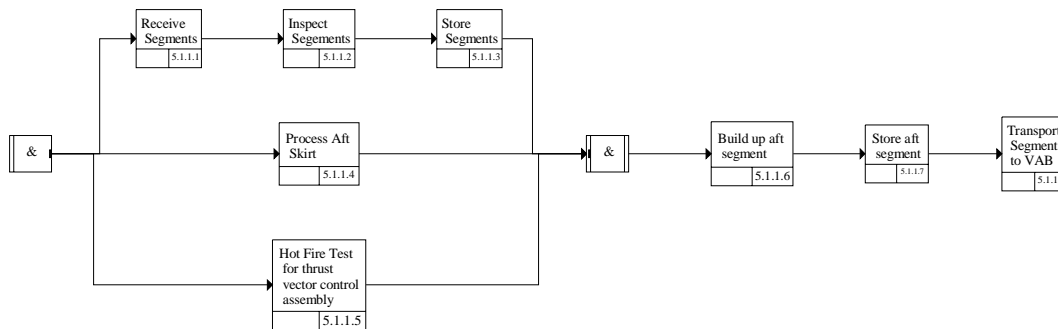

Figure 23. SRB Operations in the RPSF

6.0 Transport Shuttle to Launch Pad

The integrated shuttle including orbiter, SRBs, and ET atop the MLP are transported to the launch pad mounted to one of the crawler/transporters. The crawler transporter is driven into the bay containing the integrated shuttle and is lifted until the MLP is taken off its supports. The entire assembly then begins the 8 hour drive to one of two launch pads. The crawler/transporter follows a 130 foot wide track containing two 40 foot wide gravel paths separated by a 50 foot median. Once at the launch pad, the crawler/transporter lowers itself and lets the MLP rest on the supports at the launch pad.

75

The crawler/transporter is then removed to a safe distance but kept nearby. If bad weather is expected, the shuttle assembly can be taken back to an open bay in the VAB for protection.

7.0 Launch Pad Ops

The launch pad is where the launch takes place, final testing of systems occurs, vertical and hazardous payloads are installed, and liquid fuel is loaded into the ET. There are two launch pads used for the shuttle. The launch pads are approximately 3-4 miles from the VAB and are on the coast allowing for launches to take place over the water. This allows for the SRBs to be dropped into and later recovered from the ocean.

Activities that are hazardous or inherently dangerous are held off until the last moment they can occur. The launch pad is where many of these operations are conducted. The liquid propellant for the ET is pumped in and the hypergolic fuel for the FRCS, APU, and OMS pods uploaded. Ordinance devices are installed and activated on the launch pad to limit the opportunity for premature discharging.

Additional activities include the inspection of connections and lines to include the X-raying of the SSME hydraulic quick disconnects. The TPS is inspected where it is adjacent to moving components and on doors for proper seal. The ET is inspected for ice buildup to determine any potential hazards for the orbiter. Also, the cryogenic propellant lines are sprayed to prevent ice buildup. Lastly, any hazardous or vertically integrated payload is loaded into the payload bay while the shuttle is on the launch pad. Generally, satellites are vertically integrated. The model for launch pad operations can be seen in Figure 24.
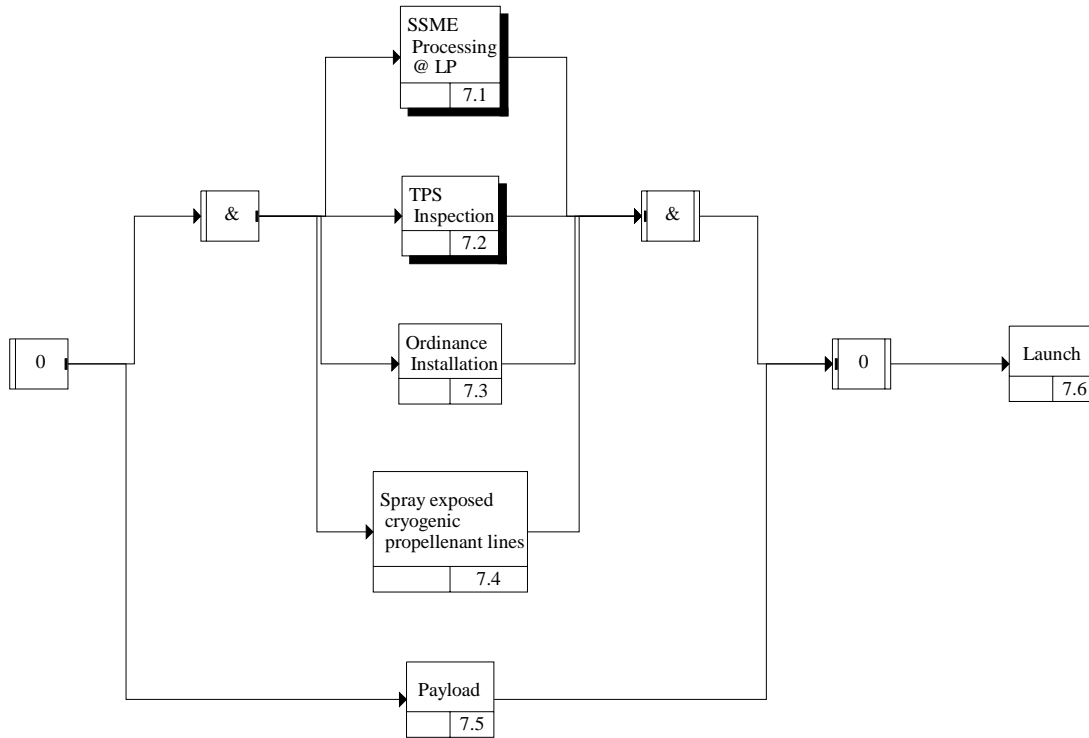
Figure 24. Launch Pad Operations

MLP refurbishment facility
The MLP is refurbished after each launch and is reused. This MLP goes from this facility to the VAB where the shuttle assembly is mated to it and then is delivered to one of the launch pads. The MLP with or without the shuttle assembly is transported on one of two crawler transporters which are another left over item from the APOLLO space program.

8.0 SRB Recovery
The SRBs touchdown within minutes after launch. However, before touchdown, the first set of parachutes is deployed form the frustrum to slow the descent. Then the frustrum is separated from the rest of the SRB and the main chute is deployed. The SRB lands in the water vertically and stays afloat due to water trapped inside. In addition, a

strobe and homing beacon are used to aid in locating each SRB. Each frustrum and

parachute is retrieved and then the parachute for each SRB. The SRBs are towed back to

the dock where they are taken to the RPSF for processing. After processing, the SRBs

are shipped via rail to Utah where they are refurbished. Since there are two ships

available for recovery, each frustrum and SRB pair can be retrieved in parallel as
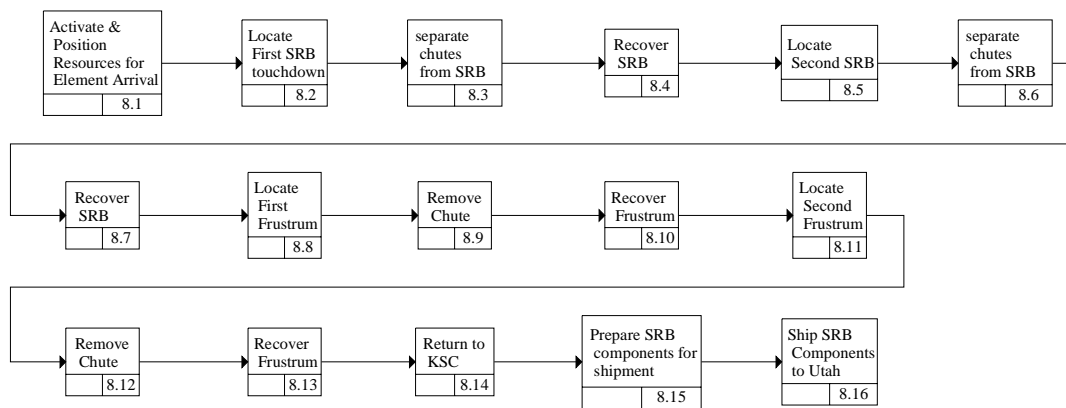
opposed to the model in Figure 25.

Figure 25. SRB Recovery Operations

Validation and Verification

A conceptual model is the "basis for judgment about a simulation's capabilities in

conditions" for which it was not tested (Pace 2000). The key to achieving such

compatibility and reliability in simulation data is the simulation conceptual model

because the simulation conceptual model is the basis for judgment about the

appropriateness (validity evaluation) of simulation data for all conditions not specifically

tested. When a model is nearing completion, it requires analysis.

The evaluation criteria are completeness, consistency, coherence, and correctness (Pace 2000). Completeness refers to addressing all entities and processes within the domain and all components of the simulation space while satisfying the specification of the simulation. Consistency ensures the entities and processes are addressed from compatible perspectives. Coherence checks to see if all elements have a function and all elements can be activated. The last criterion, correctness, is more general in nature and refers to an overall review of the model for flow and understanding (Pace 2000).

Verification comes in part from the comparison of the completed model to the requirements set forth in Chapter 3. The model was examined and an element was found for every item specified for representation. Furthermore elements of potential interest to the model purpose were addressed indicating a high level of model completeness and coherence. Real world counterparts exist for each element enabling reuse and unnecessary elements were scrubbed. Additionally, each element is addressed from the same perspective. Activities were presented from a process oriented viewpoint and entities from an object oriented viewpoint adding to the consistency of the model. Lastly, correctness is ensured by checking the overall flow of the model looking for logical flows while ensuring no disconnects exist.

The validation process began by comparing the results of the data analysis methodology to similar results generated by NASA personnel. Taking the filtered data and importing it to MS Project and developing a IDEF3 schematic, a comparison was made. The results were found to be very close confirming the concept of using the start and stop dates/times to establish precedence where none was given. By comparing NASA flow diagrams to the IDEF3 model, the data analysis method was validated.

V. Conclusions and Recommendations

In this chapter, conclusions, recommendations, and suggestions for future research will be discussed. This chapter will also re-examine the scope and limitations, then look at the threats to validity that were suggested at the beginning of the analysis, and see what materialized to see if any unforeseen conditions arose.

Conclusions

Beginning the modeling process with a detailed conceptual model is the most appropriate step. By working at the Domain Level, the baseline concepts and flows can be gathered providing insight into the data required and the data currently available. This step allows the researcher to gather facts about the system to be modeled and combine them into a format that is clear and concise.

Using the IDEF3 methodology provided an excellent format for organizing the data and presenting it in a clear model. The use of a few basic components made learning the methodology quick and easy. The IDEF3 methodology matches well with conceptual model development and is just right for the layout of process-centered diagrams. Additionally, it adds the capability to diagram object-centered views.

The use of KBSI's ProSim 7.0 provided several benefits. The software was easy to grasp and allowed for the collection of and transformation of the data directly into a IDEF3 schematic. The interface was user-friendly and provided several ways to view the data. When viewing the data in the Process Flow Node List mode, each diagram and block was represented by a single line of text on the screen. Each decomposition could be opened or closed by expanding or collapsing the tree. In this mode, it was easy to move objects around the model. Another benefit is the generation of the model in HTML

format. ProSim generates a folder that contains the model components as individual

HTML files that can be opened and viewed on any web browser. This function allows

the model to be shared with others who do not have the ProSim software.

An additional benefit of the ProSim software not realized in this effort is its

ability to integrate simulation data and be used to conduct analysis. ProSim was designed

to not only produce IDEF3 schematics but to be used to conduct simulation analysis.

How well ProSim operates in this capacity or whether it would be appropriate for use in

future research in this endeavor is unknown at this point.

Scope and Limitations

Data as expected turned out to be a limitation and provided a challenge for the

scope. In some cases, the data was too detailed but still lacking in levels of precedence.

In many cases the data was found to be difficult to track down.   Data concerning

operations outside the OPF was especially difficult to locate. Data outside the scope of

the effort had to be filtered out based on the judgment of the researcher. Additionally, the

bias and interest of those at KSC influenced this problem to some degree. Three main

ongoing concerns at KSC concern the SSMEs, TPS, and unscheduled maintenance. The

first two generated the data that was in greater detail while the last item generated data

that was outside the scope.

Threats to Validity

Due to the above listed focus at KSC, time and resources have been devoted to

collecting data associated with those areas of concern rather than all operations.

Therefore, data concerning engine operations, especially within the OPF, and the TPS exists in detailed and extensive quantities. A list of 5988 STS procedures was provided to the researchers. Of the 425 different STS procedures used to develop the current conceptual model, only 70% were found in this list.

Additionally, much data exists for unscheduled maintenance and the associated troubleshooting. KSC spends approximately 25% of shuttle turnaround time on unscheduled maintenance (McCleskey 2003). The importance of analyzing unscheduled maintenance for trends is seen in the possibility of discovering tasks that should be performed more often that may be necessary to reduce both future maintenance actions and turnaround time. These tasks are not included in this model. Some activities of concern to developers of next generation space vehicles may have been inadvertently left out since those tasks are not regularly scheduled or recognized as needing to be scheduled.

Data Analysis

The most difficult data to analyze was the data found in spreadsheets and tables. The spreadsheets allowed sorting by design disciplines, STS subsystems and procedure numbers. However, lack of textual description of the process or overall procedure (including constraint information) made model developing challenging. The researcher was left to arrange the data based on the known constraints (remove must occur before installation) and task timing (start and finish times). Without the benefit of process descriptions and constraints, many processes were modeled in parallel.

Using the supplied data, this research did serve in verifying that the methodology used to filter and scrub the data was correct. The key here was to develop a baseline model encompassing the necessary activities of a general nature that may be useful in developing a simulation for RSV ground operations. This model serves that purpose and is useful in understanding the processes involved in turning around a RSV. The level of data available was useful in this initial baseline approach but will need to be expanded for research to continue.

Suggestions for Further Study

This research effort exposed the need for further data collection and decomposition. The data sets examined to gain a baseline understanding of the operations at KSC are not sufficient enough to provide the detail needed for developing distributions about the durations and arrival rates needed for simulation development. Continued research into the collection of this data and its analysis would be beneficial to the furtherance of this effort towards the development of a simulation.

However, this effort was tasked with developing a baseline conceptual model that would be used to model various SOVs making tradeoffs between components and materials. With this end in mind, it may not be necessary to collect detailed data on all aspects of the shuttle operations, but only those deemed necessary by subject matter experts.

Additionally, continued research into unscheduled maintenance on the shuttle would be beneficial in providing greater validity to the model. By filtering out the data without further examination, some necessary model components may not have been

modeled simply because they were not scheduled. A detailed examination of the

unscheduled maintenance on the shuttle may expose those activities that should have

been included and provide a more rigorous method for filtering out unnecessary data.

Appendix C contains a more detailed listing of further research.

Appendix A: Listing of Acronyms Used in Model

Due to space constraints and the time consuming nature of data entry, many items names have been replaced with acronyms. In the body of the document, the item name is spelled out for the first use but that is not the case for the model. To help in understanding the model, this list of items and corresponding acronyms has been developed.

AFRSI	advance flexible reusable surface insulation
APS	auxiliary power system
APU	auxiliary power unit
AV	avionics
C/O	check out
CCTV	closed circuit television
CEIT	crew equipment interface test
COMM	communication
DPS	data processing system
ECLSS	environmental control life support system
ECS	environmental control system
EPD	electronic power distribution
ET	external tank
ET	external tank
FCP	fuel cell systems
FCS	flight control system
FRCS	forward reaction control system
GH2	gaseous hydrogen
GHE	ground handling equipment
GNC	guidance, navigation, and control
GOX	gaseous oxygen
GPS	global positioning system
GSE	ground system equipment
HMF	hypergol maintenance facility
HPFTP	high pressure fuel turbo pump

HPOTP	high pressure oxidizer turbo pump
HUD	heads up display
HYD	hydraulic systems
INS	instrumentation system
KSC	Kennedy Space Center
LESS	leading edge structural system
LH2	liquid hydrogen
LO2	liquid oxygen
LP	launch pad
LPFTP	low pressure fuel turbo pump
LPOTP	low pressure oxidizer turbo pump
LPS	launch processing system
MEDS	multifunction electronic display system
MCC	Mission Control Center
MEQ	mechanism
MLG	main landing gear
MLGD	main landing gear door
MLP	mobile launch pad
MPS	main propulsion system
MSBLS	microwave scanning beam landing system
MTU	master timing unit
NC	numerical control
NDE	nondestructive evaluation
NLG	nose landing gear
NLGD	nose landing gear door
ODS	orbiter docking system
OEL	orbiter electrical
OHE	orbiter handling equipment
OME	orbiter maneuvering engine
OMEF	orbiter main engine maintenance facility
OMEMF	orbiter main engine maintenance facility
OML	outer mold line
OMS	orbiter maneuvering system
OPF	orbiter processing facility
OPS	operations
OSO	orbiter support ops
OTC	orbiter conductor operations
PCMMU	post code master modulation unit
PLBD	payload bay door
PRSD	power reactant storage and distribution
PVD	purge, vent, and drain
PYR	pyrotechnics

QC	quality engineering
R&R	remove and replace
RCC	reinforced carbon-carbon
RCS	reaction control system
RPSF	rotation, processing, and surge facility
RSI	reusable surface insulation
SCOPALS	scanner closeout preprocessor and lofting system
SME	shuttle main engine
SRB	solid rocket booster
SSME	space shuttle main engine
SSME	space shuttle main engine
STR	structures
TCID	test configuration identifier document
TPS	thermal protection system
TVC	thrust vector control
VAB	vehicle assembly building
WCS	waste collection system
WSB	waste spray boiler
XDUCER	crossducer

Appendix B: Baseline Conceptual Model for RSV Ground Ops

This section includes all the diagrams included in the model in the order generated by ProSim when exported as a RTF document. The RTF was then converted to a MS Word document and imported into this thesis. This collection of diagrams is meant to aid in understanding the model by providing a physical versus electronic version. This collection of diagrams is meant to supplement the electronic version of the model and is not intended to replace it. The electronic version is made available with this document to aid in further research efforts and model development.
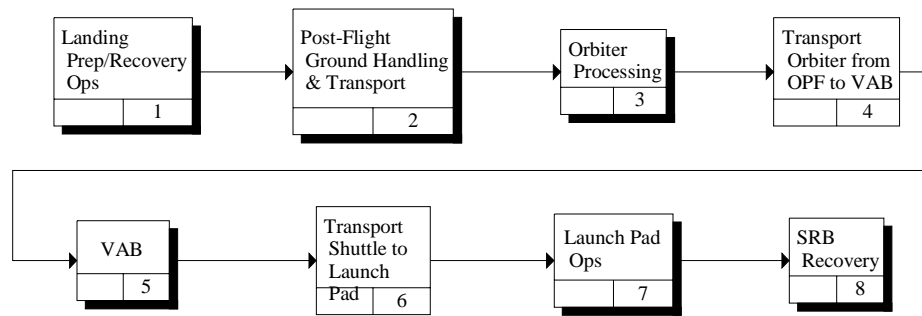
Figure B-1. Overarching Shuttle

Description

There are thousands of activities performed during the course of a normal OPF processing flow. For the most part, these can be grouped into the following three major activities: Preparing the external surfaces (e.g. the thermal protective tiles) for the next mission. Because of improvements in tile repair and manufacturing processes, along with modifications to the thermal protection system, this work is not typically the critical path.

Payload related work in the Orbiter's mid-body or payload bay and crew cabin. This activity includes downloading the previous mission payload and its integration hardware, and preparing the payload bay and crew cabin for the upcoming payload. This activity is typically either the critical path or at least a major influence on the critical path.

Work in and around the Orbiter's Aft Engine Compartment. This activity includes, safing the OMS Pods and Auxiliary Power Units, removing the three main engines, installing the next set of engines and performing pre-flight testing of the Aft Engine Compartment's many systems. Like the payload related work, this activity is either the critical path or a major influence.

Not mentioned above are many other important tasks that must be integrated into the flow such as: safing the FRCS , changing the tires; polishing the windows; trouble-shooting the previous mission's in-flight problems and a host of minor problems that occur during the course of any OPF flow; and performing approved modifications. (Cates Shuttle Processing Overview.ppt)

Orbiter Processing Facility (OPF)

There are three OPF high-bays available for Orbiter Processing. These are referred to as Bay 1, Bay 2, and Bay 3. Bays 1 & 2 are co-located and Bay 3 is located a short distance from them. The orbiter processing flow begins at OPF roll-in and ends at OPF roll-out to the Vehicle Assembly Building. The orbiter is processed in one of the three OPF bays for approximately 80 Calendar days (62 Workdays) of OPF Processing.
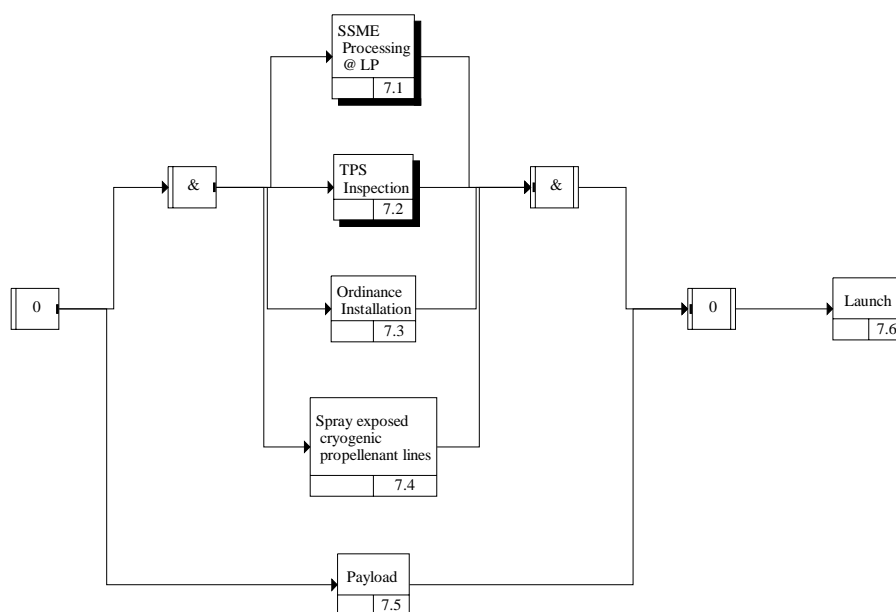
89
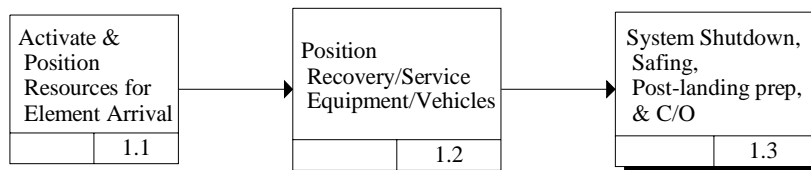
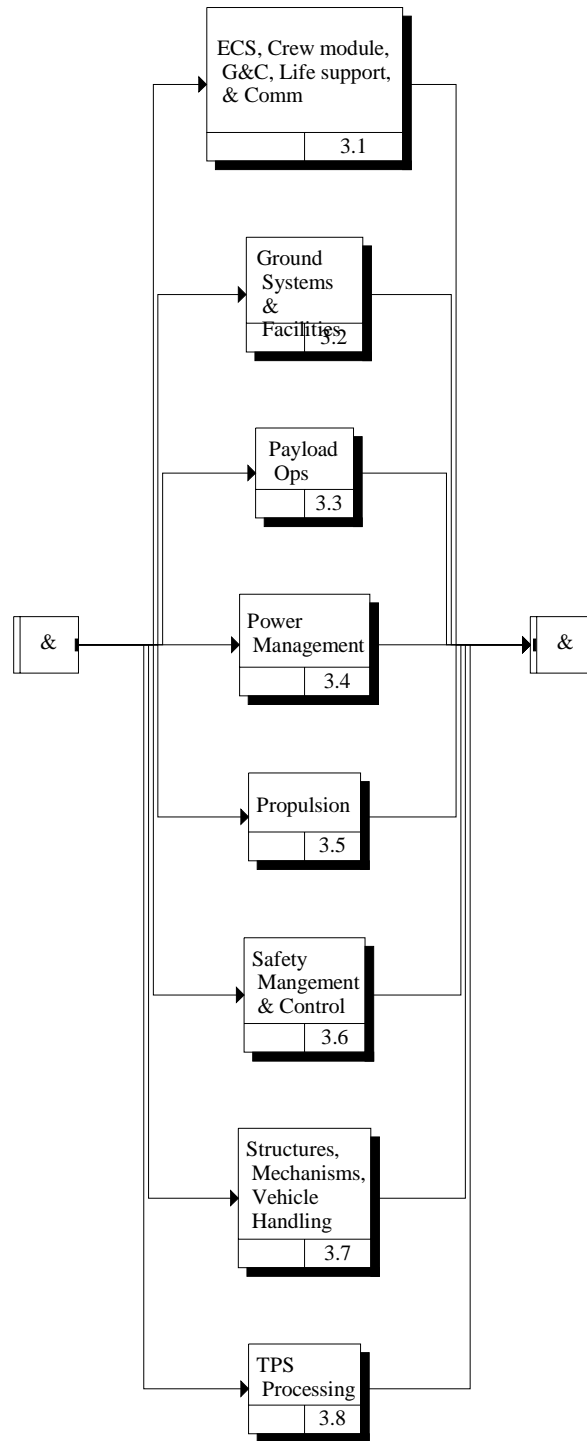**Figure B-2. Element L&R Ops**

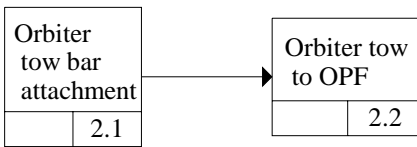**Figure B-3. Launch Pad Ops**

Figure B-4. Orbiter Processing
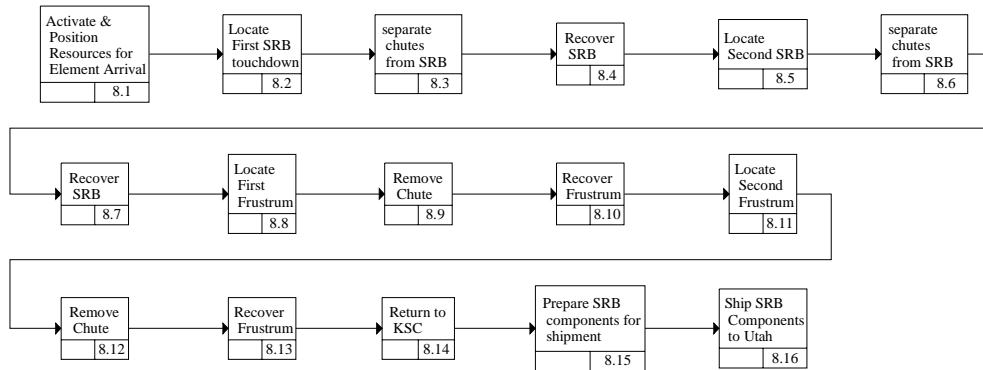
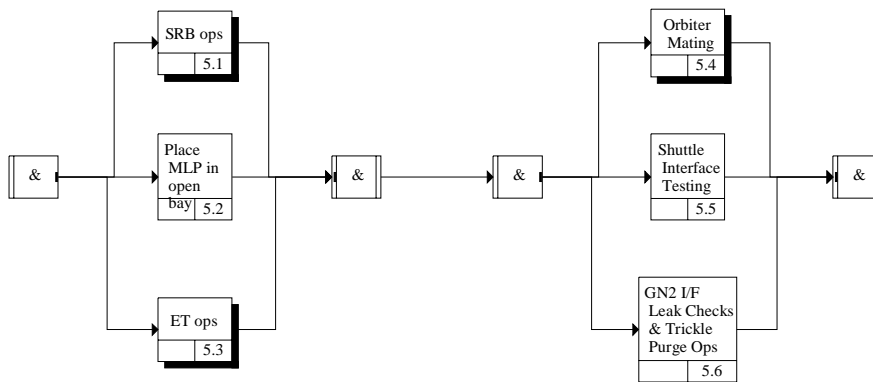**Figure B-5. Post-Flight Ground Handling**
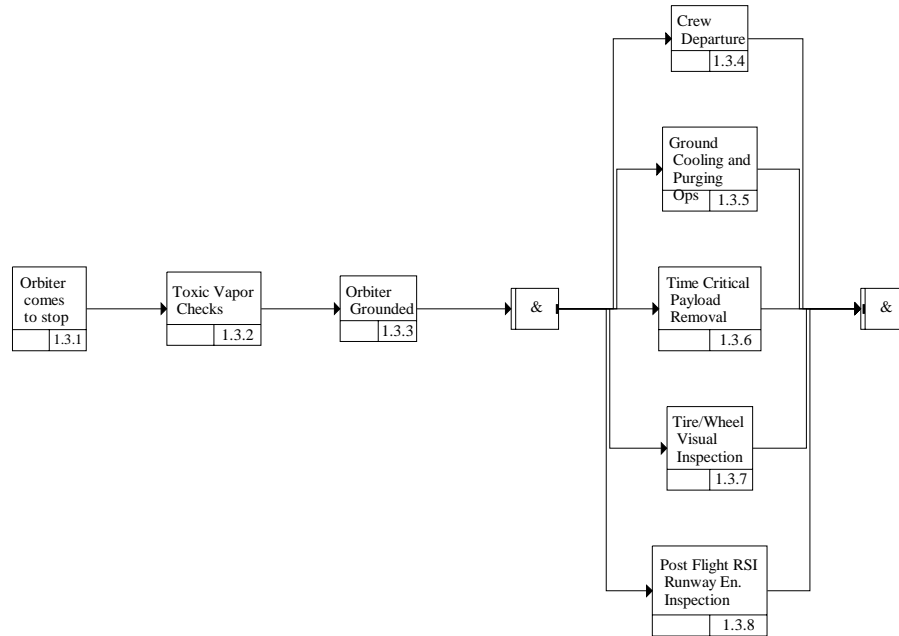

Figure B-6. SRB Ops

Figure B-7. VAB Ops
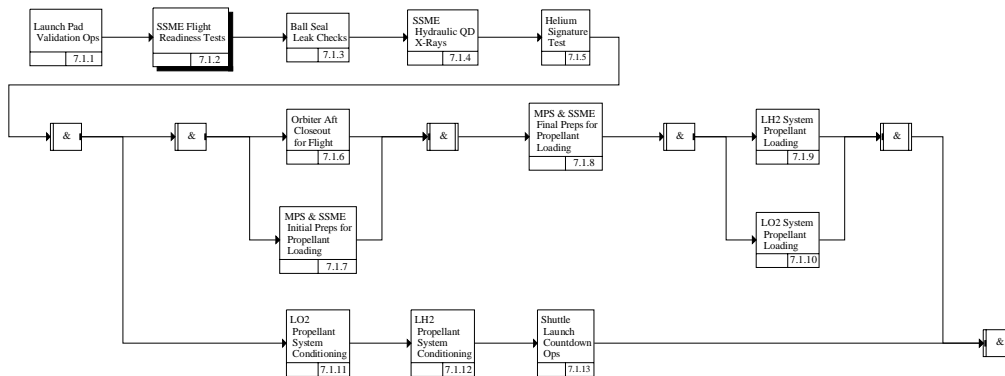
Figure B-8. System Shutdown, Safing, and C/O
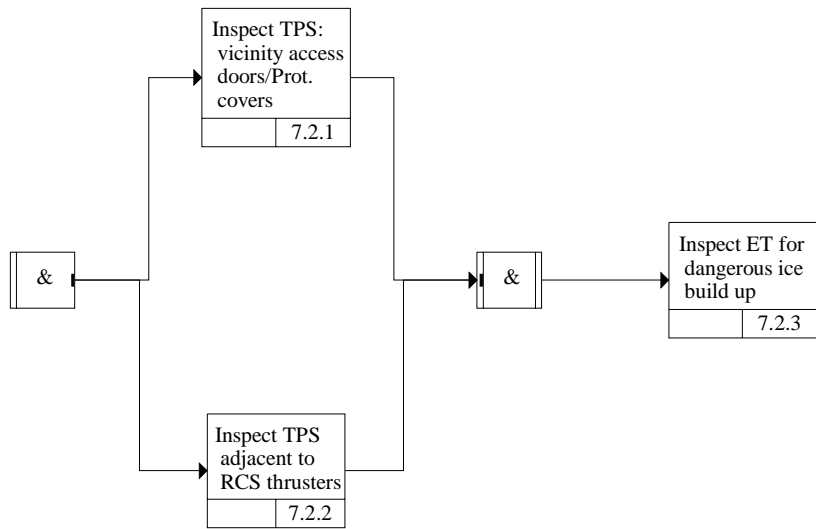

Figure B-9. SSME Processing @ LP

```
                 ┌────────────────┐
                 │ Inspect TPS:   │
                 │  vicinity access│
                 │ doors/Prot.    │
                 │ covers         │
                 ├──────┬─────────┤
                 │      │  7.2.1  │
                 └──────┴─────────┘
                                              ┌────────────────┐
                                              │ Inspect ET for │
   ┌──────┐                      ┌──────┐     │ dangerous ice  │
   │  &   │                      │  &   │     │ build up       │
   └──────┘                      └──────┘     ├──────┬─────────┤
                                              │      │  7.2.3  │
                                              └──────┴─────────┘
                 ┌────────────────┐
                 │ Inspect TPS    │
                 │ adjacent to    │
                 │ RCS thrusters  │
                 ├──────┬─────────┤
                 │      │  7.2.2  │
                 └──────┴─────────┘
```

Figure B-10. TPS Inspection

94
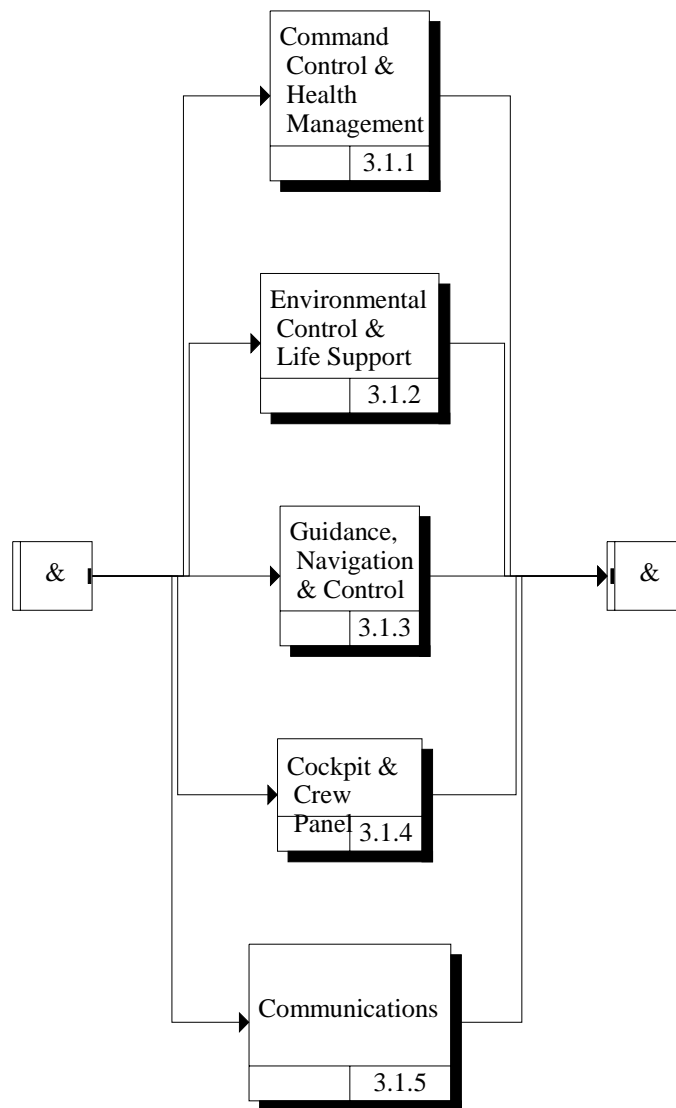
Figure B-11. ECS, Crew module, GNC, Life support, & Comm
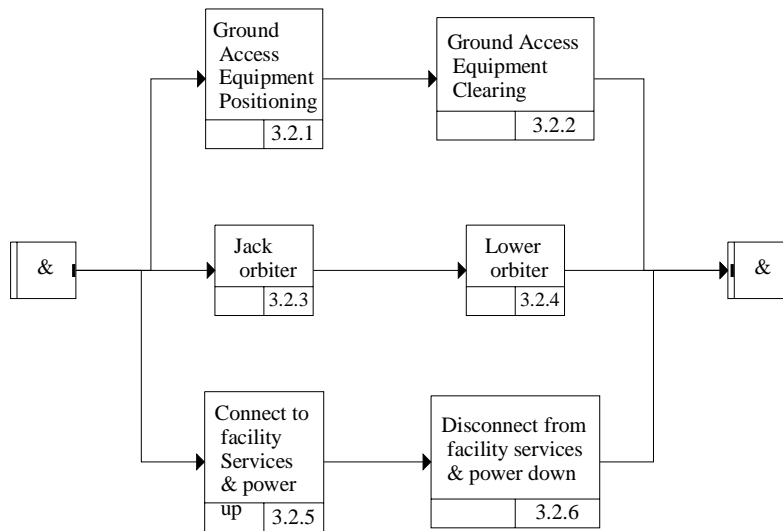
Figure B-12. Ground Systems & Facilities
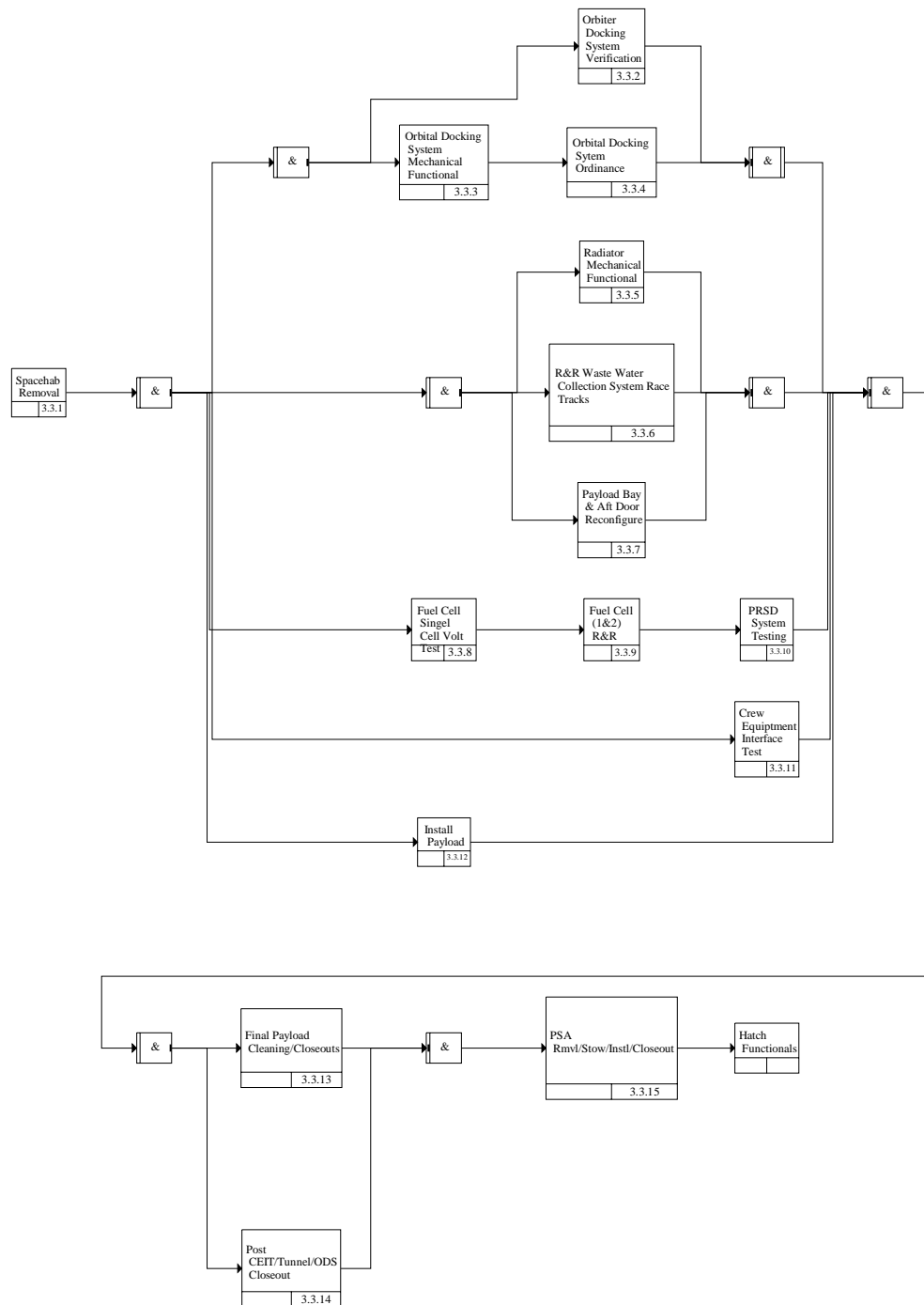
Figure B-13. Payload Accommodations

97
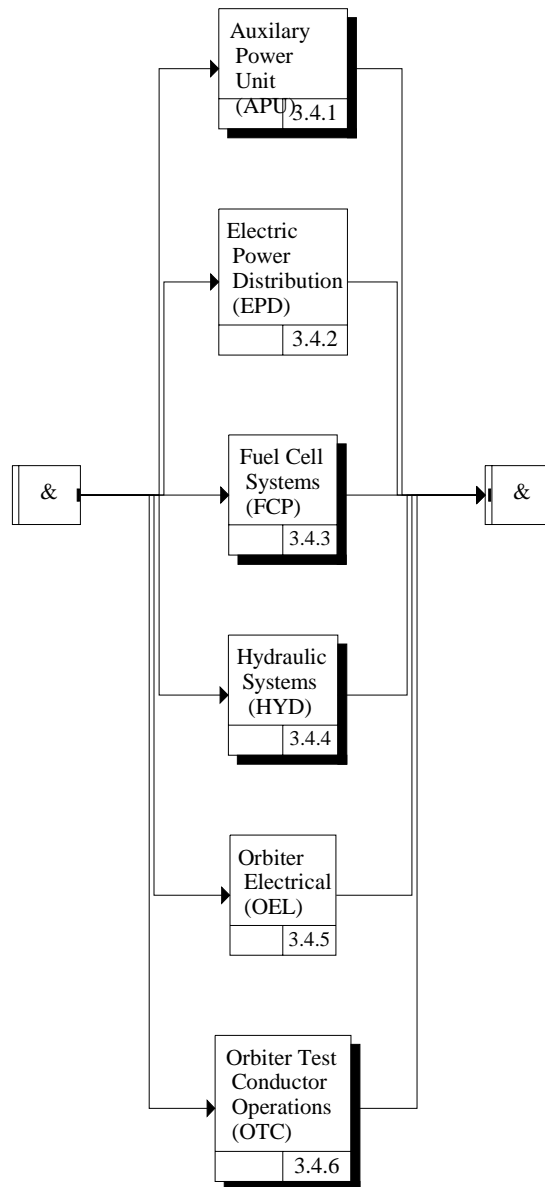
Figure B-14. Power Management
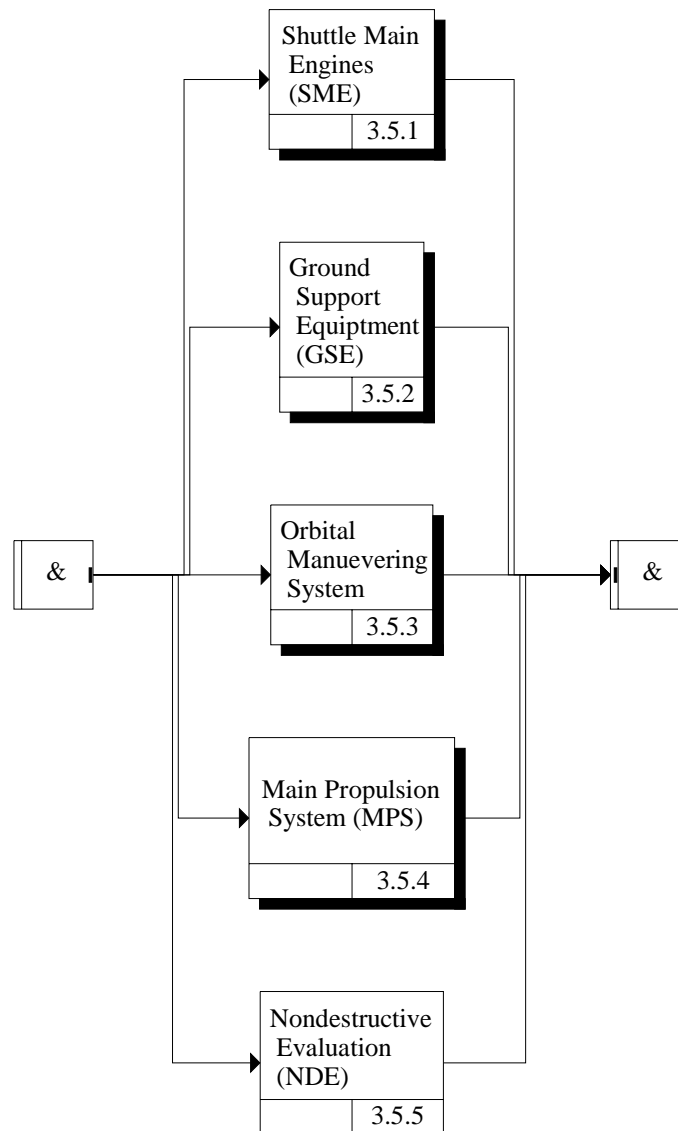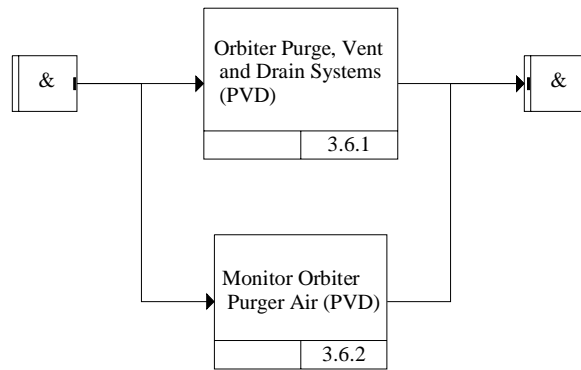
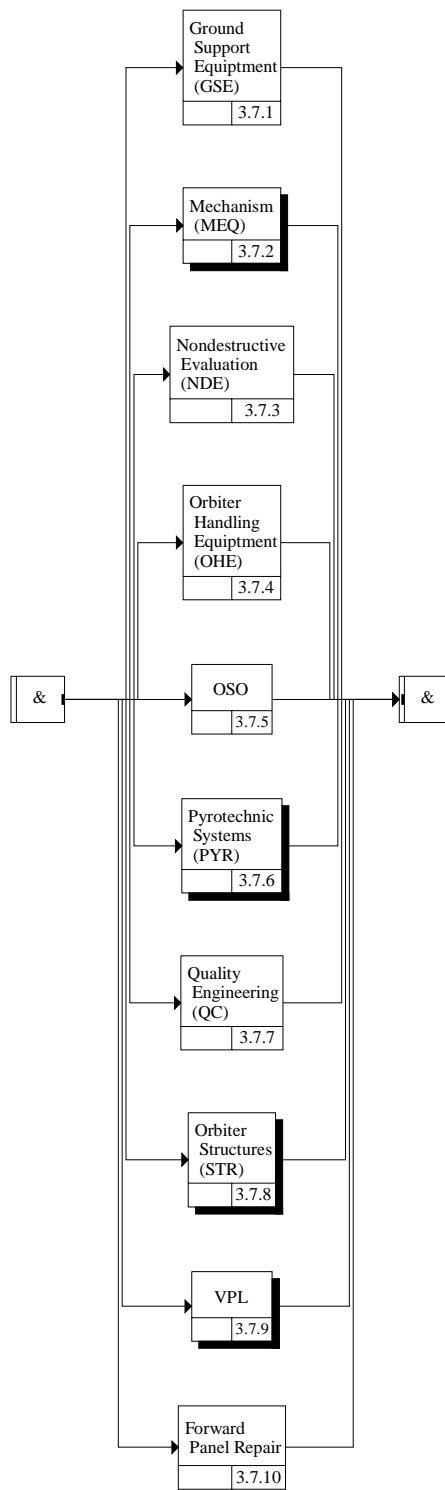**Figure B-15. Propulsion**

Figure B-16. Safety Management & Control

Figure B-17. Structures, Mechanisms, Vehicle Handling

Figure B-18. TPS Processing
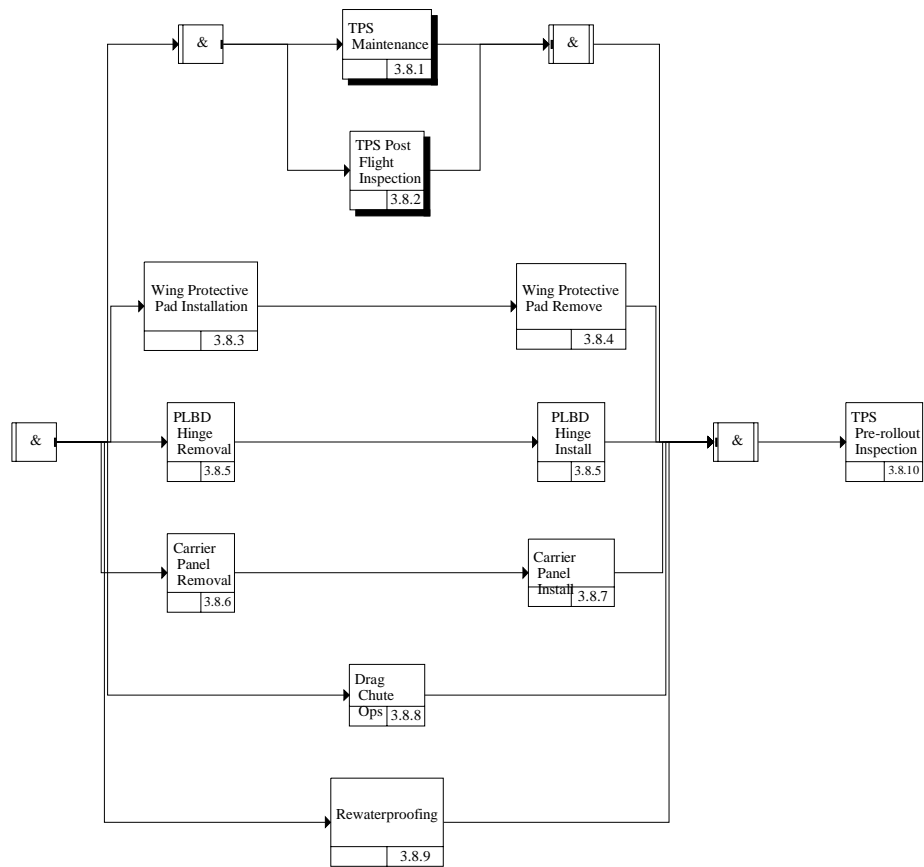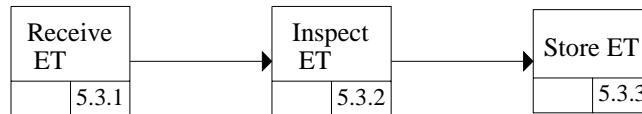
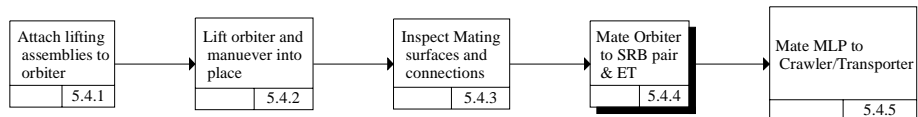| &		TPS Maintenance	3.8.1	&

	TPS Post Flight Inspection	3.8.2

Wing Protective Pad Installation	3.8.3	Wing Protective Pad Remove	3.8.4

&	PLBD Hinge Removal	3.8.5	PLBD Hinge Install	3.8.5	&	TPS Pre-rollout Inspection	3.8.10

Carrier Panel Removal	3.8.6	Carrier Panel Install	3.8.7

Drag Chute Ops	3.8.8

Rewaterproofing	3.8.9

Figure B-18. TPS Processing

Receive ET	5.3.1	Inspect ET	5.3.2	Store ET	5.3.3

Figure B-19. ET OPs

Attach lifting assemblies to orbiter	5.4.1	Lift orbiter and manuever into place	5.4.2	Inspect Mating surfaces and connections	5.4.3	Mate Orbiter to SRB pair & ET	5.4.4	Mate MLP to Crawler/Transporter	5.4.5

Figure B-20. Orbiter Mating
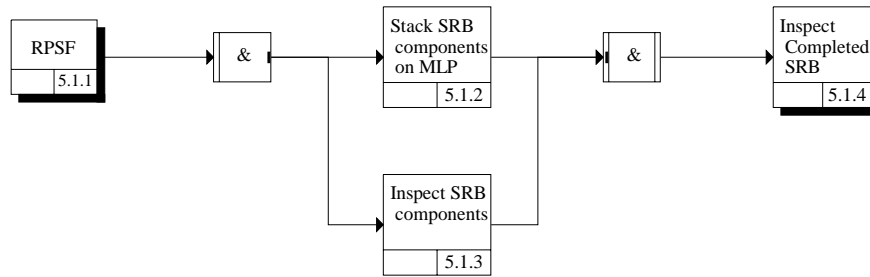
Figure B-21. SRB Ops
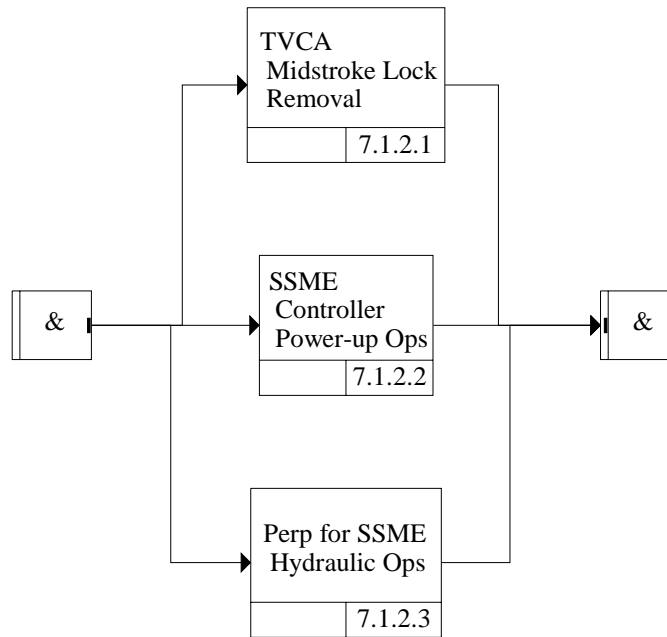
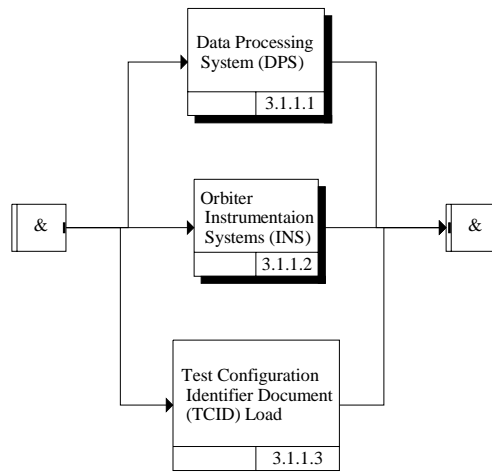**Figure B-22. SSME FRTs**
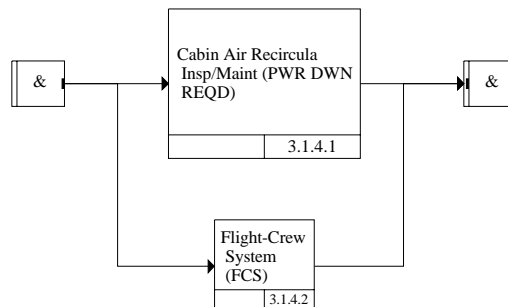
Figure B-23. Cockpit & Crew Panel
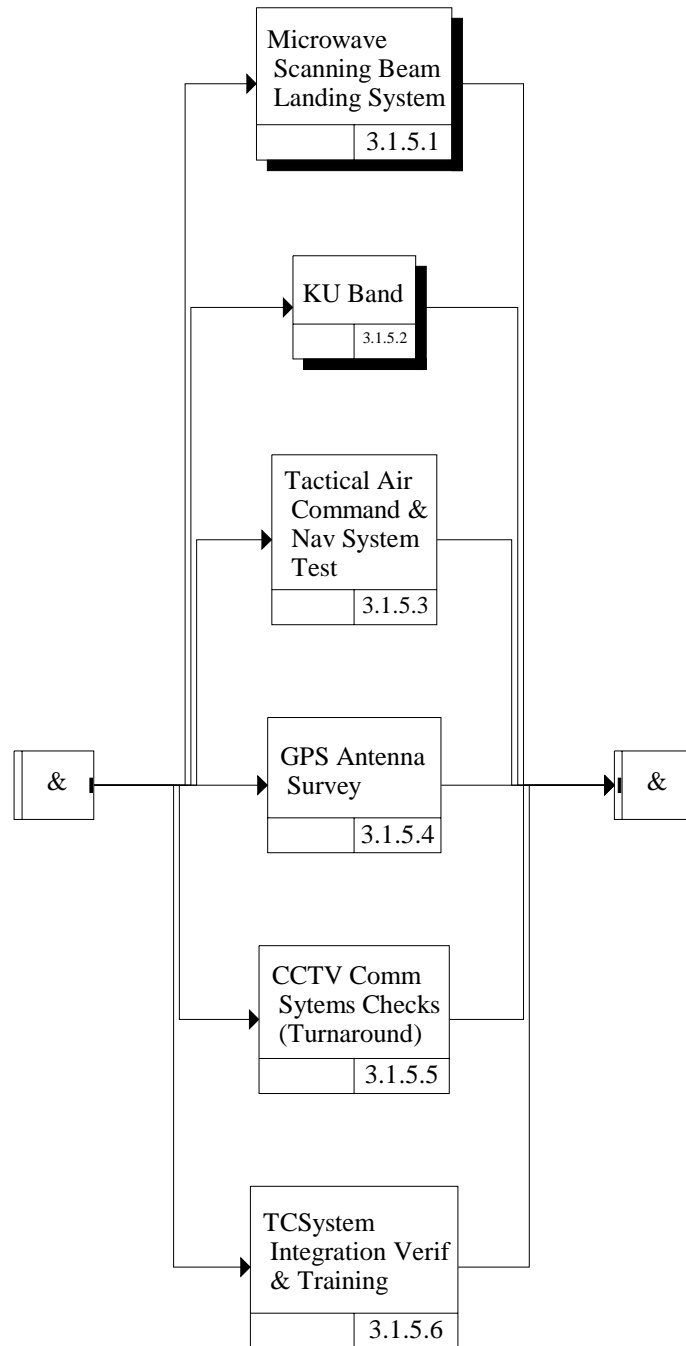
Figure B-24. Command Control & Health Management

```
┌─────────────────────┐
│ Microwave           │
│ Scanning Beam       │
│ Landing System      │
├──────────┬──────────┤
│          │ 3.1.5.1  │
└──────────┴──────────┘

┌─────────────────────┐
│ KU Band             │
├──────────┬──────────┤
│          │ 3.1.5.2  │
└──────────┴──────────┘

┌─────────────────────┐
│ Tactical Air        │
│ Command &           │
│ Nav System          │
│ Test                │
├──────────┬──────────┤
│          │ 3.1.5.3  │
└──────────┴──────────┘

┌─────────────────────┐
│ GPS Antenna         │
│ Survey              │
├──────────┬──────────┤
│          │ 3.1.5.4  │
└──────────┴──────────┘

┌─────────────────────┐
│ CCTV Comm           │
│ Sytems Checks       │
│ (Turnaround)        │
├──────────┬──────────┤
│          │ 3.1.5.5  │
└──────────┴──────────┘

┌─────────────────────┐
│ TCSystem            │
│ Integration Verif   │
│ & Training          │
├──────────┬──────────┤
│          │ 3.1.5.6  │
└──────────┴──────────┘
```

Figure B-25. Communications
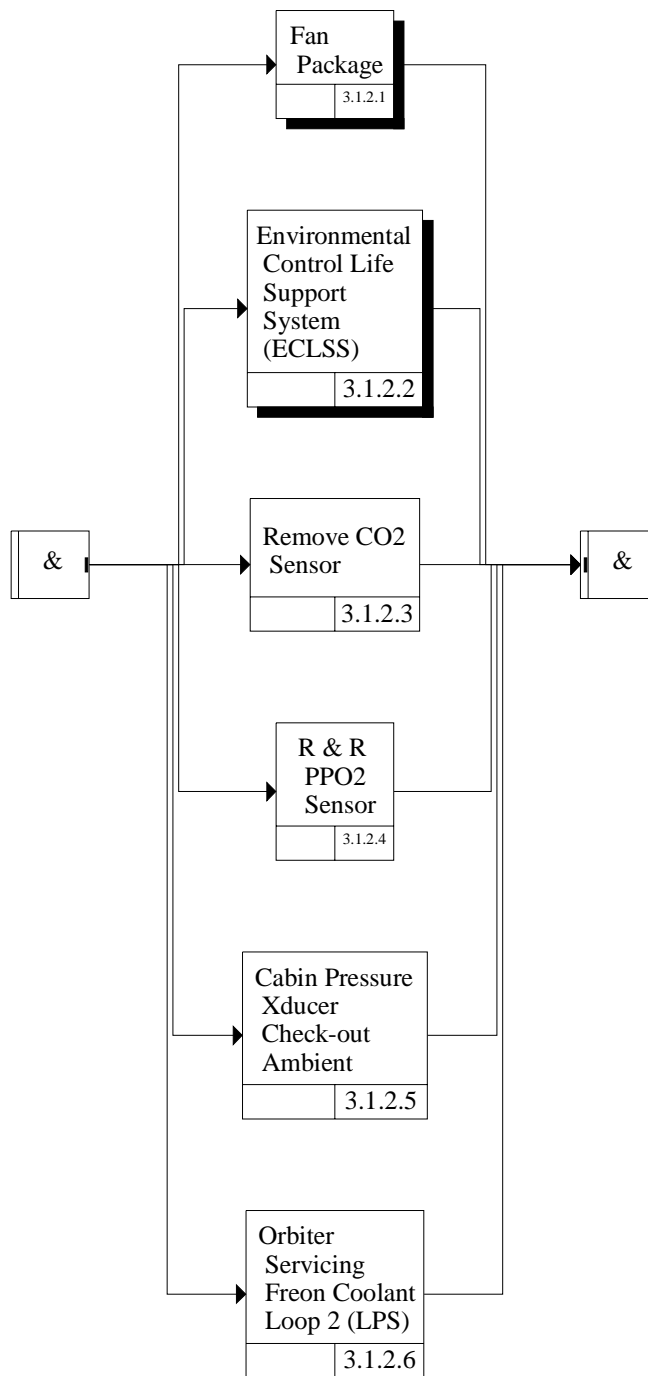
Figure B-26. Environmental Control & Life Support

106
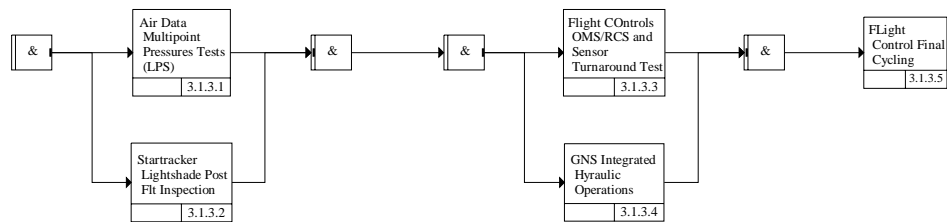
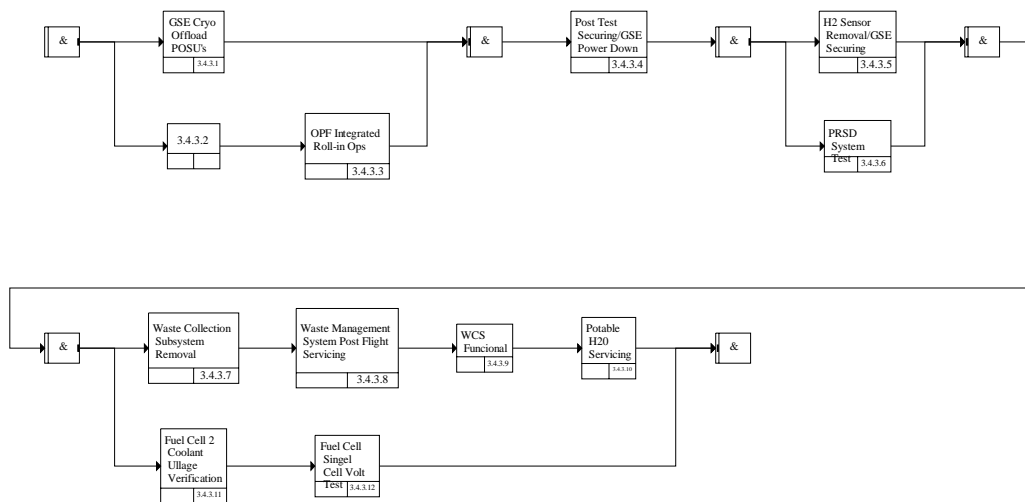**Figure B-27. GNC**
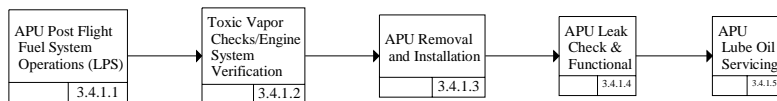
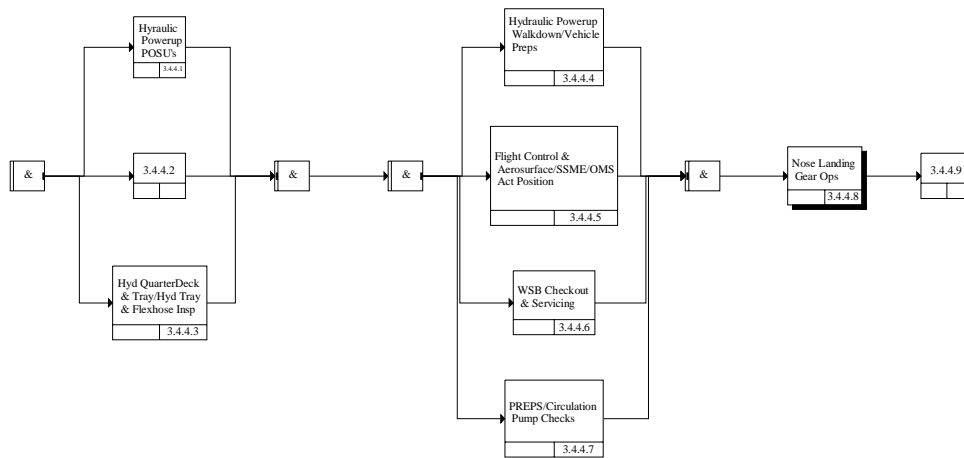**Figure B-28. APU**

Figure B-29. FCP
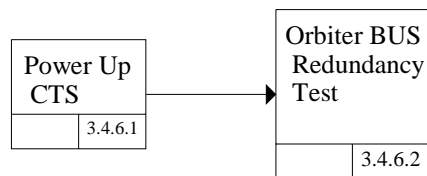
107

Figure B-30. HYD

Figure B-31. OTC
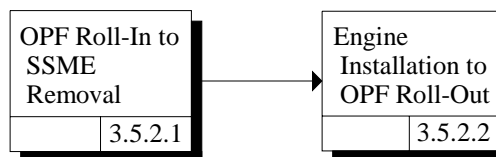
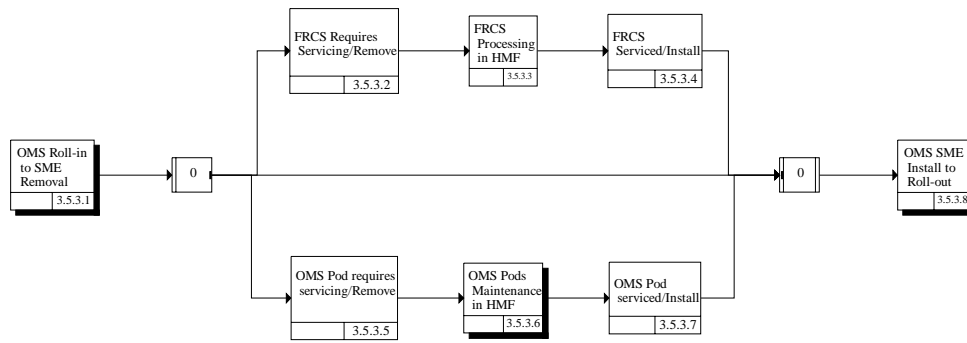**Figure B-32. GSE Propulsion**
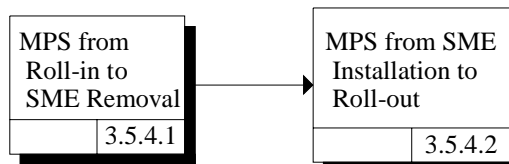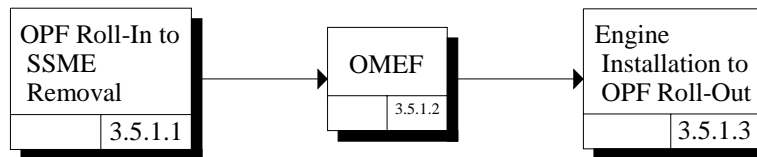

Figure B-33. MPS

Figure B-34. OMS

FRCS Requires Servicing/Remove 3.5.3.2	FRCS Processing in HMF 3.5.3.3	FRCS Serviced/Install 3.5.3.4		

| OMS Roll-in to SME Removal 3.5.3.1 | 0 | | 0 | OMS SME Install to Roll-out 3.5.3.8 |

OMS Pod requires servicing/Remove 3.5.3.5	OMS Pods Maintenance in HMF 3.5.3.6	OMS Pod serviced/Install 3.5.3.7		

Figure B-34. OMS

OPF Roll-In to SSME Removal 3.5.1.1	→	OMEF 3.5.1.2	→	Engine Installation to OPF Roll-Out 3.5.1.3

Figure B-35. SSME

	Orbiter Docking System (ODS) Inspections 3.7.2.2			
Payload Bay Door & Latch Functional 3.7.2.1	&	Main Landing Gear (MLG) Assembly 3.7.2.3	&	NLG/MLG Exend/Retract 3.7.2.5
	Nose Landing Gear Assembly 3.7.2.4	Landing Gear Door Functional 3.7.2.6	&	External Tank (ET) Door Operations 3.7.2.9
	Radiator Operations 3.7.2.7	P/L Radiator Mechanical Functional 3.7.2.8		

Figure B-36. MEQ

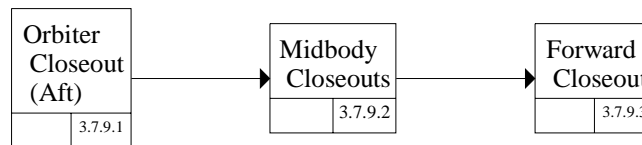**Figure B-37. STR**
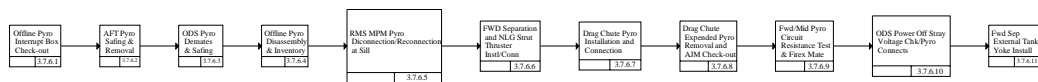
Figure B-38. PYR

Figure B-39. VPL

110
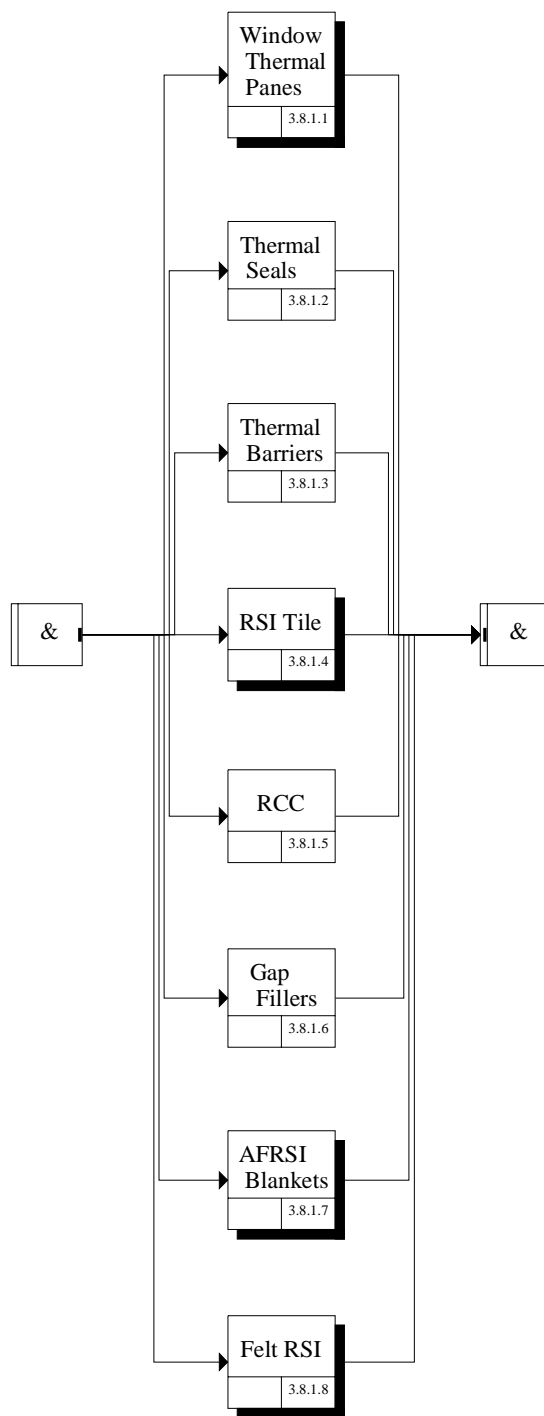
Figure B-40. TPS Maintenance
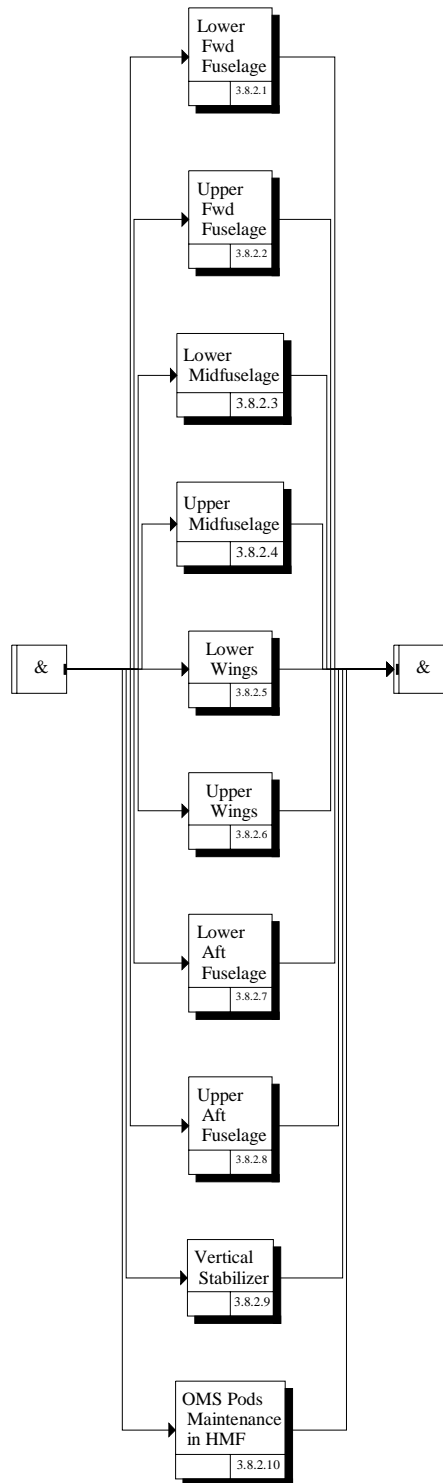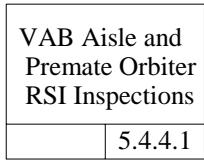
Figure B-41. Post Flight Inspections

```
┌─────────────────┐
│ VAB Aisle and   │
│ Premate Orbiter │
│ RSI Inspections │
├────────┬────────┤
│        │ 5.4.4.1│
└────────┴────────┘
```

Figure B-42. Orbiter Mating Ops

```
┌──────────┐      ┌──────────┐      ┌──────────┐
│ SRB Leak │      │ SRB Seal │      │ SRB      │
│ Check    │─────▶│ Decay    │─────▶│ Alignment│
│          │      │ Check    │      │ Check    │
├──────┬───┤      ├──────┬───┤      ├──────┬───┤
│      │5.1.4.1│   │      │5.1.4.2│   │      │5.1.4.3│
└──────┴───┘      └──────┴───┘      └──────┴───┘
```
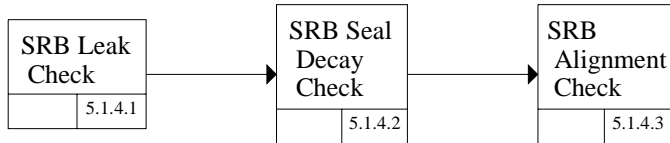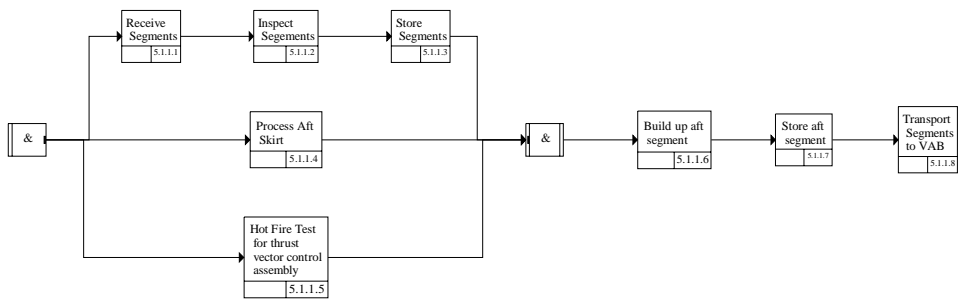
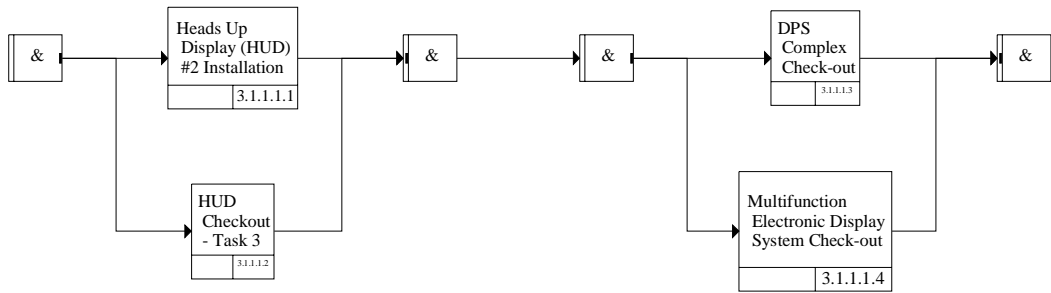**Figure B-43. Inspect Completed SRB**

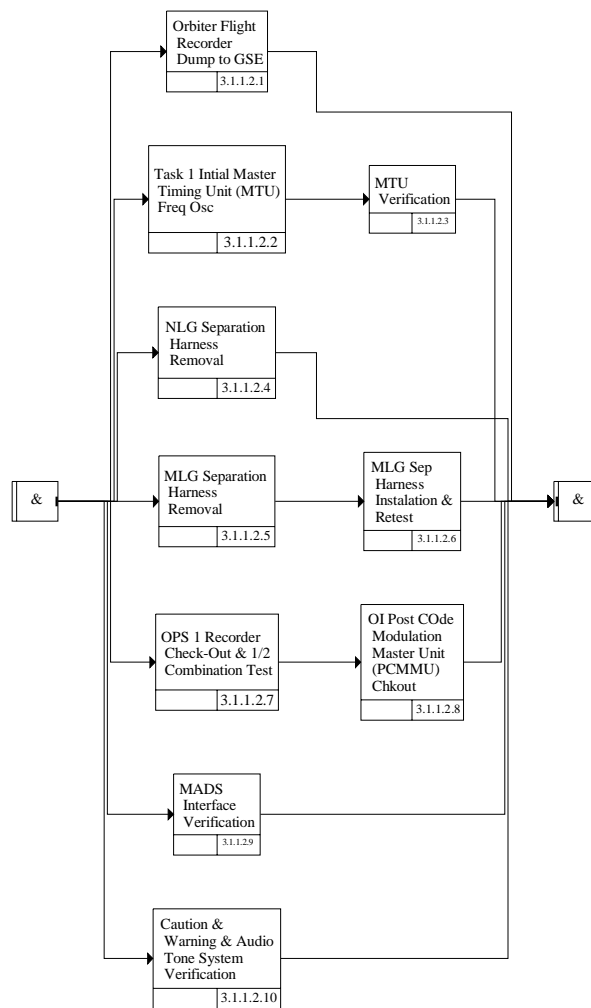**Figure B-44. RPSF**

Figure B-45. Data Processing System (DPS)
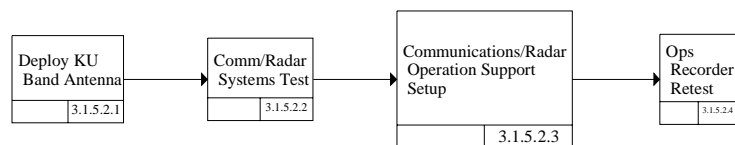
113
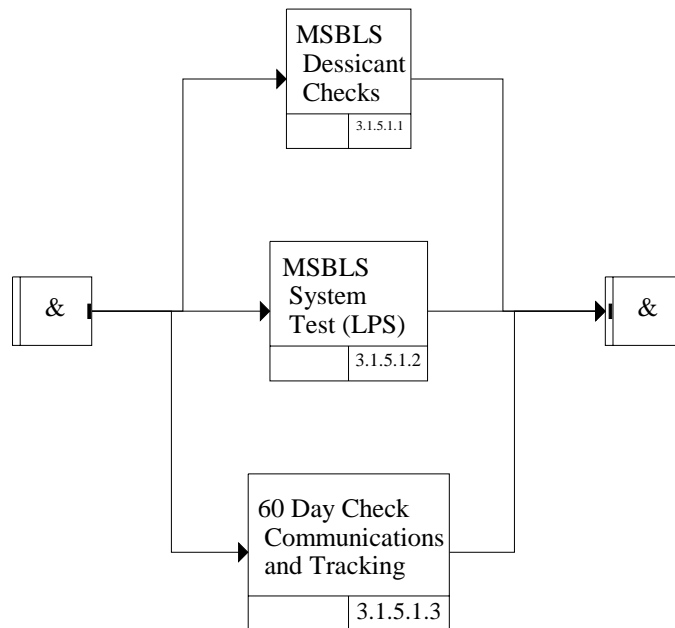
Figure B-46. INS

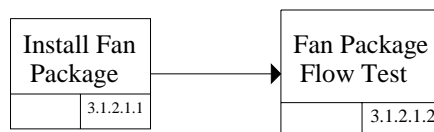**Figure B-47. KU Band**

Figure B-48. MSBLS
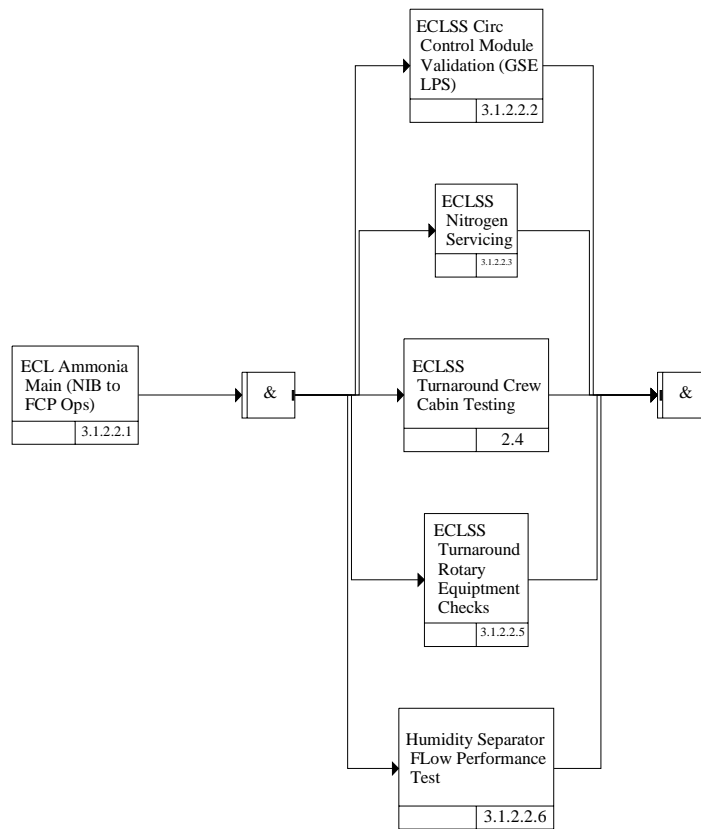
Figure B-49. ECLSS
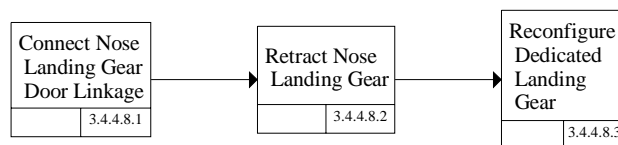

Figure B-50. Fan Package
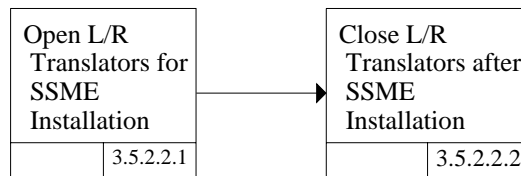

Figure B-51. NLG Ops

```
┌──────────────────────┐          ┌──────────────────────┐
│ Open L/R             │          │ Close L/R            │
│ Translators for      │─────────▶│ Translators after    │
│ SSME                 │          │ SSME                 │
│ Installation         │          │ Installation         │
├──────────────┬───────┤          ├──────────────┬───────┤
│          3.5.2.2.1   │          │          3.5.2.2.2   │
└──────────────────────┘          └──────────────────────┘
```

Figure B-51. GSE SME Install to exit

```
┌──────────────────┐       ┌──────────────────┐       ┌──────────────────┐
│ Primary and      │       │ Open L/R         │       │ Close L/R        │
│ Vernier RCS      │       │ Translators for  │       │ Translators after│
│ Thruster         │──────▶│ SSME Removal     │──────▶│ SSME Removal     │
│ Chamber GM       │       │                  │       │                  │
├────────┬─────────┤       ├────────┬─────────┤       ├────────┬─────────┤
│      3.5.2.1.1   │       │      3.5.2.1.2   │       │      3.5.2.1.3   │
└──────────────────┘       └──────────────────┘       └──────────────────┘
```
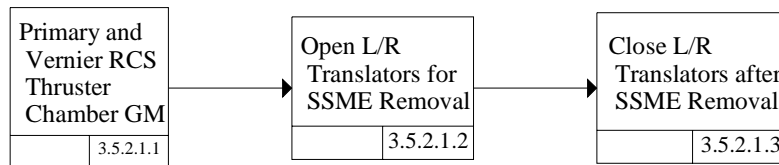
Figure B-52. GSE to SSME Removal

```
                    ┌──────────────────┐
                    │ MPS Vacuum       │
                    │ Jacketed Line    │
                    │ Checks           │
                    ├──────────┬───────┤
                    │      3.5.4.1.1   │
                    └──────────────────┘

                    ┌──────────────────┐
                    │ Install MPS      │
                    │ Protective       │
  ┌─────┐           │ Covers           │          ┌─────┐        ┌──────────────────┐
  │  &  │──────────▶├──────────┬───────┤─────────▶│  &  │───────▶│ MPS Leak and     │
  └─────┘           │      3.5.4.1.2   │          └─────┘        │ Function Test    │
                    └──────────────────┘                        ├──────────┬───────┤
                                                                │      3.5.4.1.5   │
                    ┌──────────────────┐                        └──────────────────┘
                    │ Post FLight      │
                    │ MPS Line         │
                    │ Inspection       │
                    ├──────────┬───────┤
                    │      3.5.4.1.3   │
                    └──────────────────┘

                    ┌──────────────────┐
                    │ MPS GSE          │
                    │ Installation for │
                    │ HE Tank Fill     │
                    ├──────────┬───────┤
                    │      3.5.4.1.4   │
                    └──────────────────┘
```
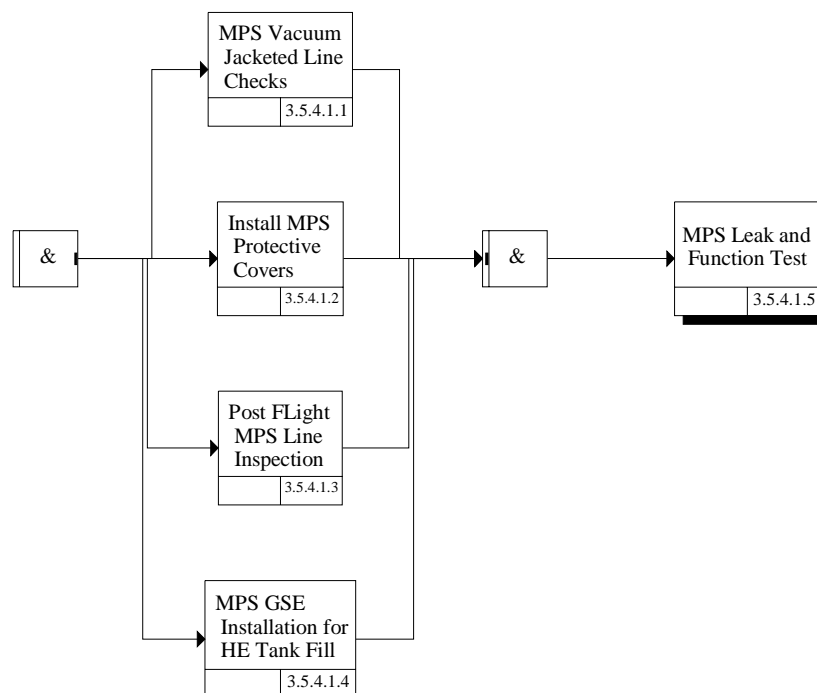
Figure B-53. MPS to SME Removal

Figure B.54. MPS SME Install to Roll-out

| 17-inch Disc Tiploads and Inspections (LPS) 3.5.4.2.1 | → | GH2 Pressure System Filter R&R 3.5.4.2.2 | → | MPS/SSME Integrated Ops 3.5.4.2.3 | → | MPS/SSME Final Configuration 3.5.4.2.4 |
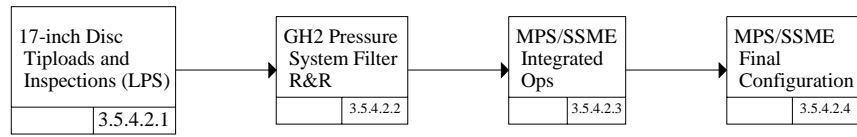
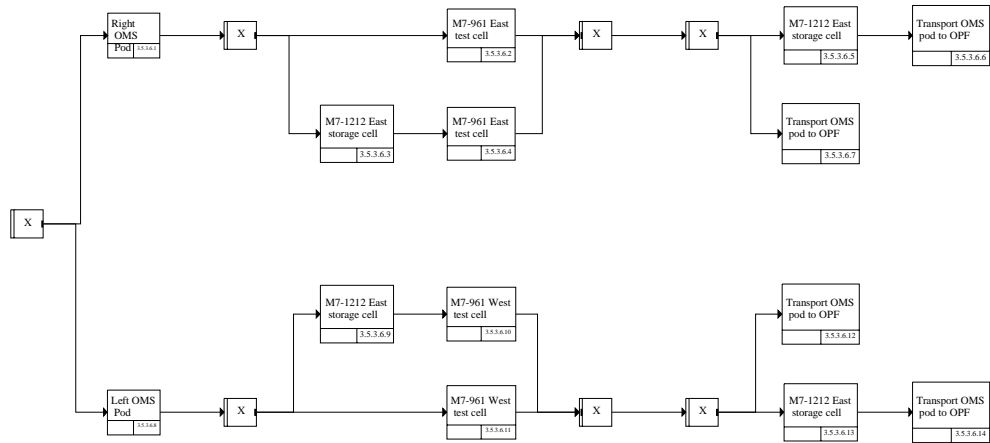**Figure B.54. MPS SME Install to Roll-out**

Figure B-55. OMS Pods

Figure B-55. OMS Pods

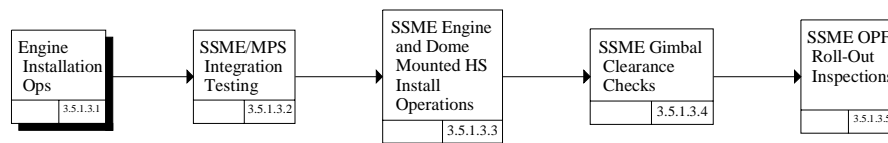## Figure B-56. OMS to SME Removal
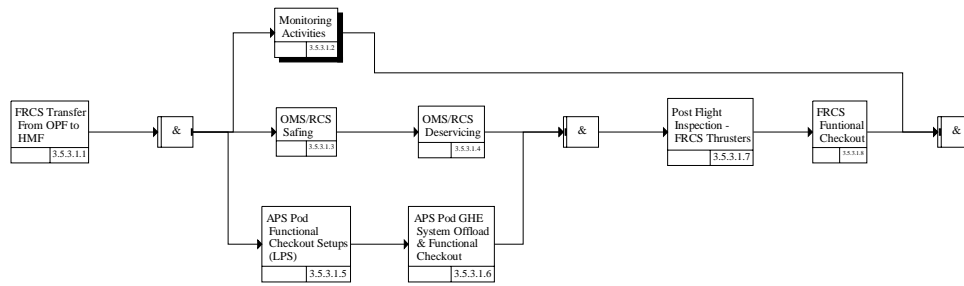
Figure B-56. OMS to SME Removal
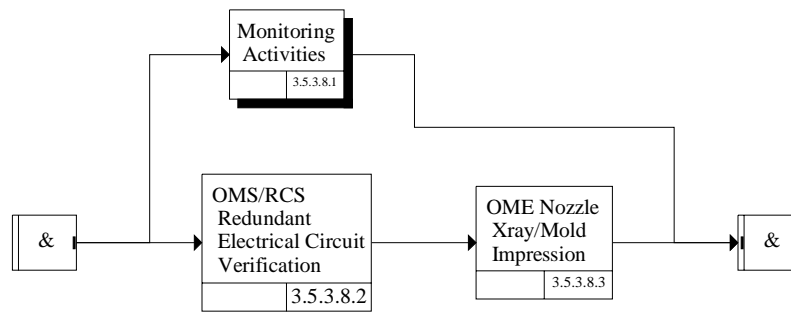
Figure B-57. OMS Post SME Installation

Figure B-58. Engine Installation to OPF Roll-Out

Figure B-59. OMEF

Figure B-60. OPF Roll-In to SSME Removal

```
┌─────────────────┐     ┌─────────────────┐     ┌─────────────────┐     ┌─────────────────┐
│ OPF Bay Open for│     │ Helium          │     │ SSME            │     │ SSME            │
│ Normal Work     │────▶│ Baggie Leak     │────▶│ Drying          │────▶│ Inspections and │
│                 │     │ Check           │     │ Operatons       │     │ Checkouts in    │
│                 │     │                 │     │                 │     │ OPF             │
│      3.5.1.1.1  │     │      3.5.1.1.2  │     │      3.5.1.1.3  │     │      3.5.1.1.4  │
└─────────────────┘     └─────────────────┘     └─────────────────┘     └─────────────────┘
```

```
              ┌───┐     ┌─────────────────┐     ┌───┐     ┌─────────────────┐
              │ & │     │ SSME Heat       │     │ & │     │ SSME            │
              │   │────▶│ Shield Removal  │────▶│   │────▶│ Removal         │
              └───┘     │ Operations      │     └───┘     │ Operations      │
                        │      3.5.1.1.5  │               │      3.5.1.1.7  │
                        └─────────────────┘               └─────────────────┘
                        ┌─────────────────┐
                        │ SSME            │
                        │ Post-Flight Low │
                        │ Pressure Pump   │
                        │ Torque Checks   │
                        │      3.5.1.1.6  │
                        └─────────────────┘
```

Figure B-60. OPF Roll-In to SSME Removal

```
┌─────────────────┐     ┌─────────────────┐     ┌─────────────────┐
│ ET Doors        │     │ Close ET        │     │ Cycle ET        │
│ to              │────▶│ Doors           │────▶│ Doors           │
│ Centerline      │     │ (TPS            │     │                 │
│      3.7.2.9.1  │     │ OPS) 3.7.2.9.2  │     │      3.7.2.9.3  │
└─────────────────┘     └─────────────────┘     └─────────────────┘
```
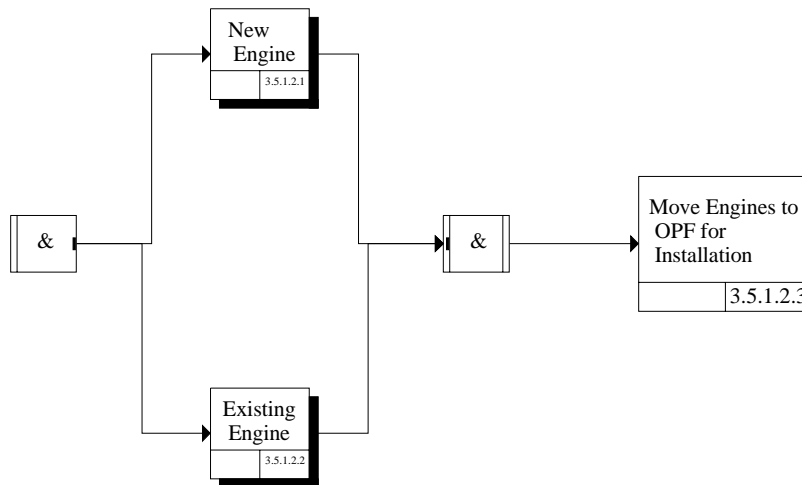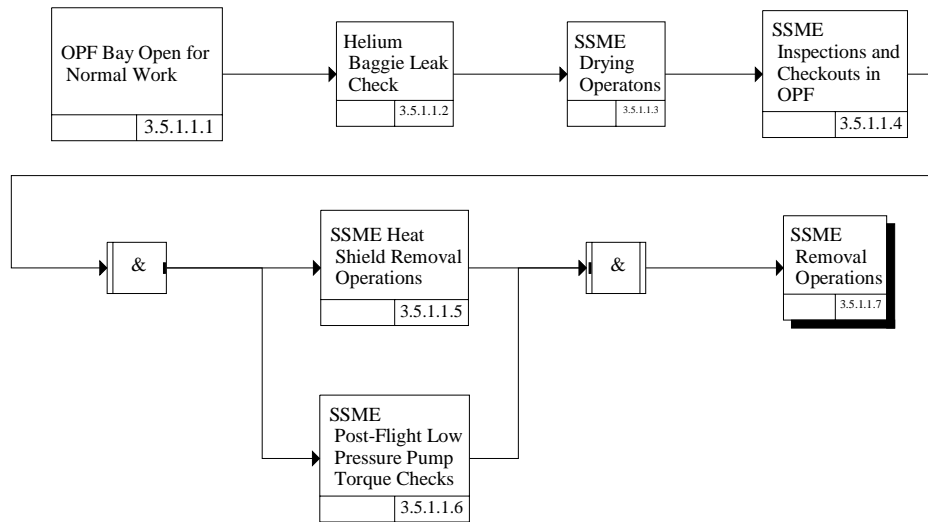
Figure B-61. ET Door Operations

```
┌─────────────────┐     ┌─────────────────┐     ┌─────────────────┐     ┌─────────────────┐
│ MLG            │     │ MLG Wheel &     │     │ MLG Strut       │     │ Pin LH/RH       │
│ Wheel/Tire     │     │ Tire Assembly   │     │ Hydraulic Level │     │ MLG             │
│ Assembly       │────▶│ Installation    │────▶│ Chek & GN2      │────▶│ Actuator        │
│ Removal/Brake  │     │                 │     │ Leak Checks     │     │                 │
│ Inspection     │     │      3.7.2.3.2  │     │      3.7.2.3.3  │     │      3.7.2.3.4  │
│      3.7.2.3.1 │     └─────────────────┘     └─────────────────┘     └─────────────────┘
└─────────────────┘
```

Figure B-61. MLG Assembly

```
┌─────────────────┐     ┌─────────────────┐     ┌─────────────────┐
│ NLG Strut       │     │ NLG Wheel       │     │ Remove          │
│ Hyraulic        │     │ Assembly        │     │ LH/RH NLG       │
│ Level Checks    │────▶│ Recertification │────▶│ Tire            │
│                 │     │ Inspection      │     │                 │
│      3.7.2.4.1  │     │      3.7.2.4.2  │     │      3.7.2.4.3  │
└─────────────────┘     └─────────────────┘     └─────────────────┘
```
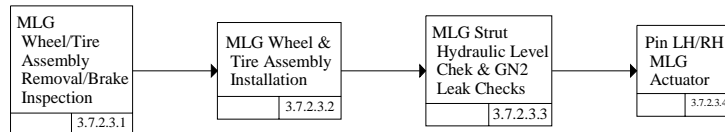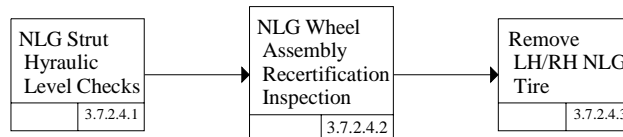
Figure B-62. NLG Assembly

120
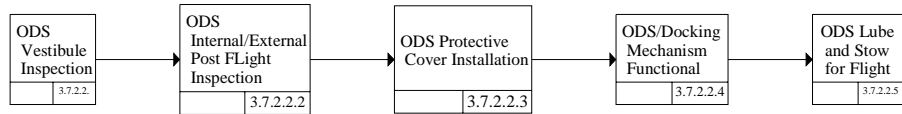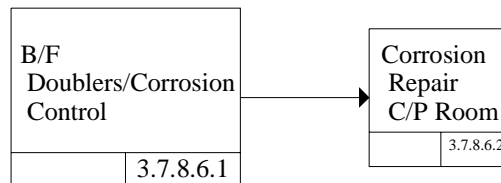
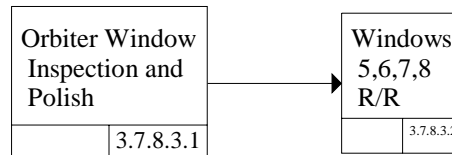**Figure B-63. ODS Inspections**

Figure B-64. Corrosion

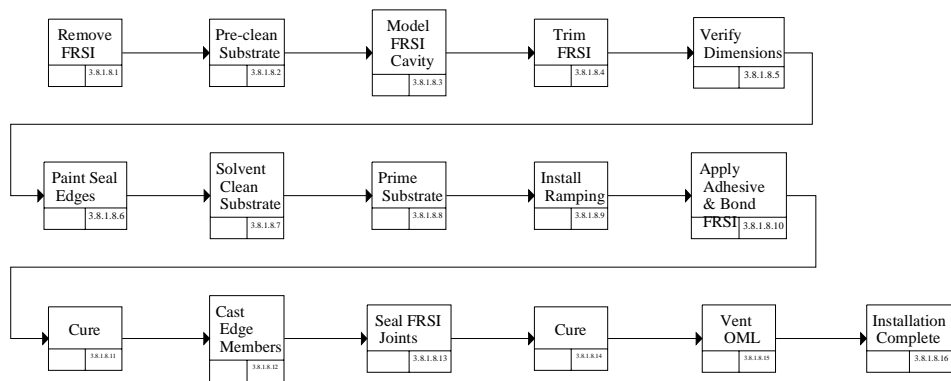**Figure B-65. Windows**
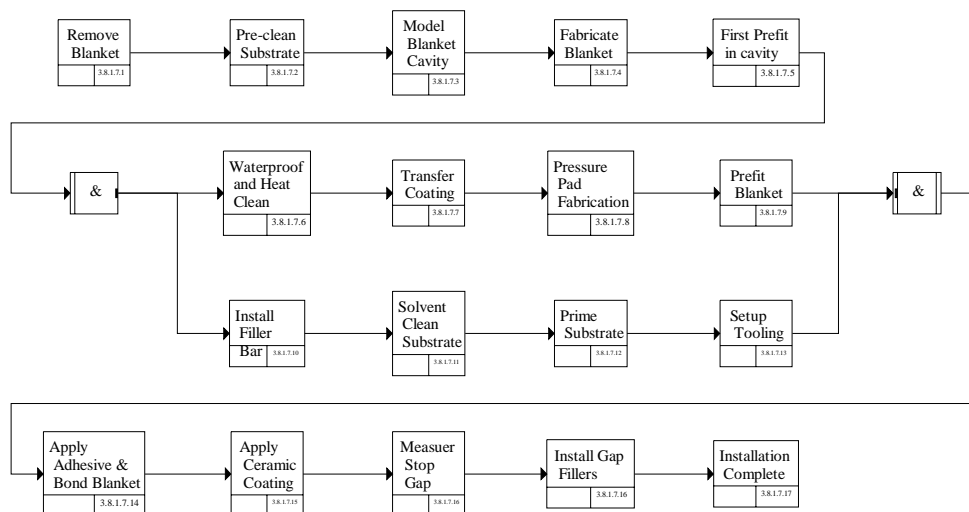
Figure B-66. AFRSI Blanket Maintenance
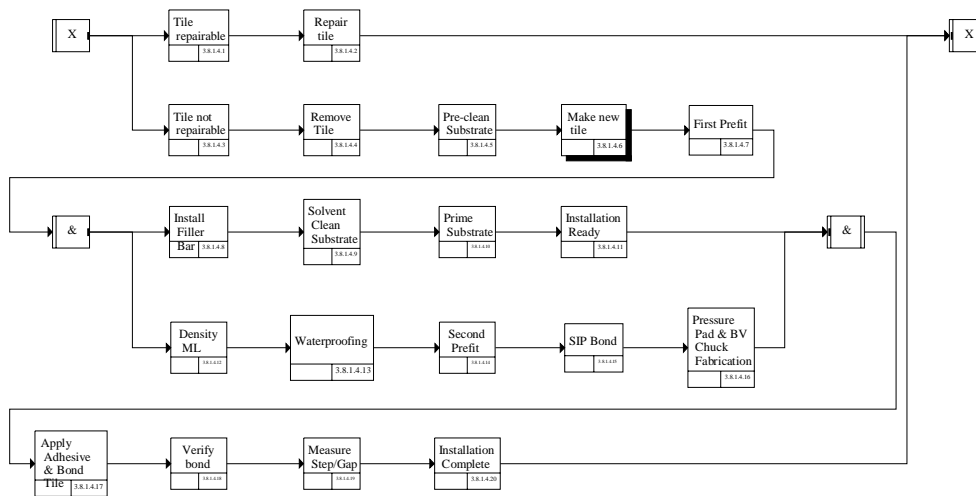
121

Figure B-67. FRSI Maintenance

Remove FRSI (3.8.1.8.1) → Pre-clean Substrate (3.8.1.8.2) → Model FRSI Cavity (3.8.1.8.3) → Trim FRSI (3.8.1.8.4) → Verify Dimensions (3.8.1.8.5)

Paint Seal Edges (3.8.1.8.6) → Solvent Clean Substrate (3.8.1.8.7) → Prime Substrate (3.8.1.8.8) → Install Ramping (3.8.1.8.9) → Apply Adhesive & Bond FRSI (3.8.1.8.10)

Cure (3.8.1.8.11) → Cast Edge Members (3.8.1.8.12) → Seal FRSI Joints (3.8.1.8.13) → Cure (3.8.1.8.14) → Vent OML (3.8.1.8.15) → Installation Complete (3.8.1.8.16)

Figure B-67. FRSI Maintenance

Figure B-68. Tile Replacement

X → Tile repairable (3.8.1.4.1) → Repair tile (3.8.1.4.2) → X

Tile not repairable (3.8.1.4.3) → Remove Tile (3.8.1.4.4) → Pre-clean Substrate (3.8.1.4.5) → Make new tile (3.8.1.4.6) → First Prefit (3.8.1.4.7)

& → Install Filler Bar (3.8.1.4.8) → Solvent Clean Substrate (3.8.1.4.9) → Prime Substrate (3.8.1.4.10) → Installation Ready (3.8.1.4.11) → &

Density ML (3.8.1.4.12) → Waterproofing (3.8.1.4.13) → Second Prefit (3.8.1.4.14) → SIP Bond (3.8.1.4.15) → Pressure Pad & BV Chuck Fabrication (3.8.1.4.16)

Apply Adhesive & Bond Tile (3.8.1.4.17) → Verify bond (3.8.1.4.18) → Measure Step/Gap (3.8.1.4.19) → Installation Complete (3.8.1.4.20)

Figure B-68. Tile Replacement

Figure B-69. Windows

Remove Windows (3.8.1.1.1) → Polish Windows (3.8.1.1.2) → Install Windows (3.8.1.1.3) → Inspect Windows for Glare (3.8.1.1.4) → Inspect Seals/Barriers (3.8.1.1.5)

Figure B-69. Windows

122
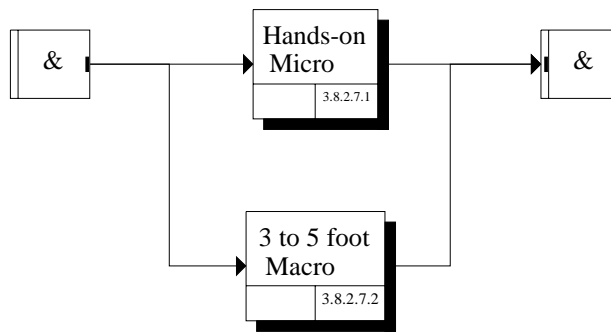
Figure B-70. Lower Aft Fuselage
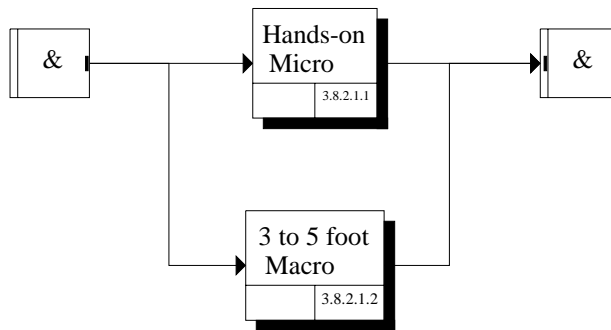
Figure B-71. Lower Forward Fuselage
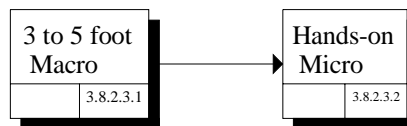
Figure B-72. Lower Midbody Fuselage

123
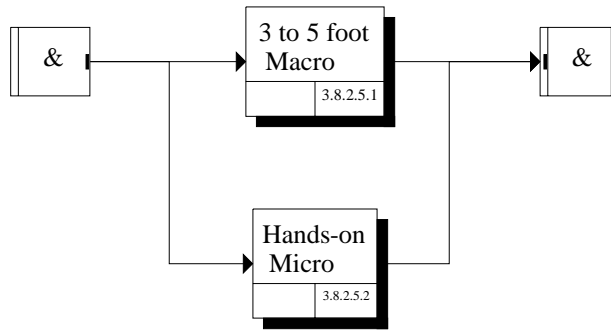
Figure B-74. Lower Wing
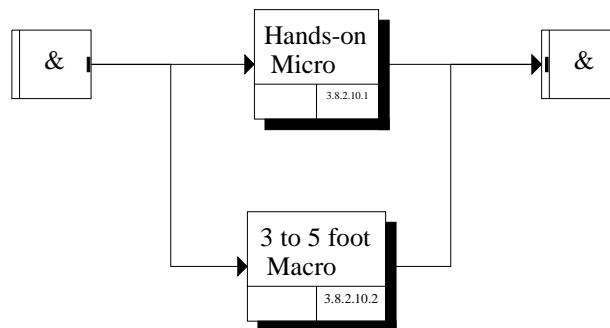
Figure B-75. OMS Pods
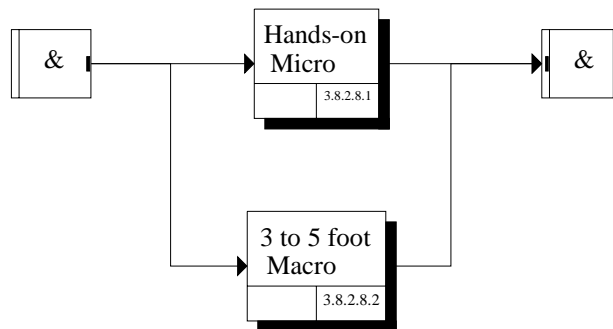
Figure B-76. Upper Aft Fuselage

124
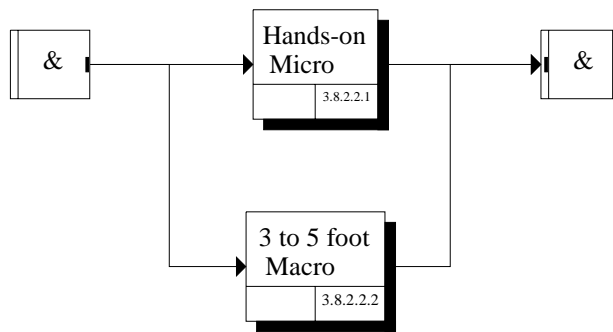
Figure B-77. Upper Forward Fuselage
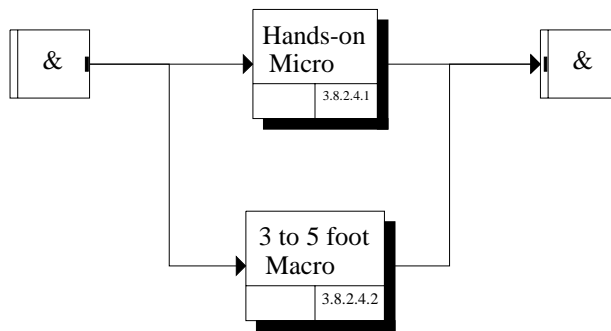
Figure B-78. Upper Midbody Fuselage
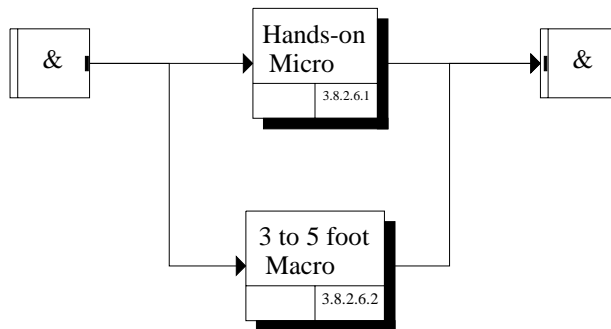
Figure B-79. Upper Wing
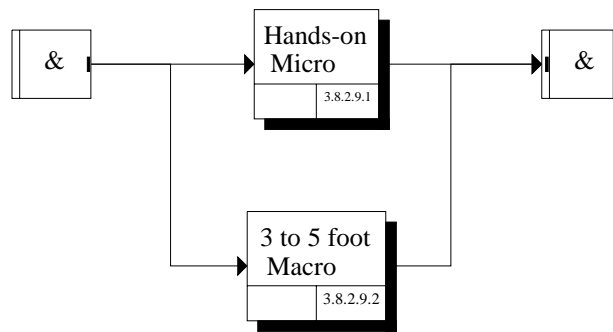
Figure B-80. Vertical Stabilizer
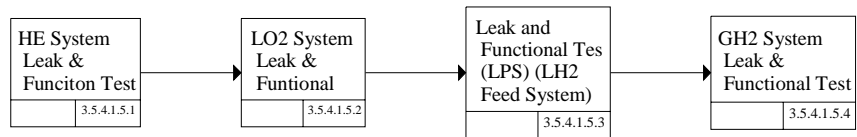
Figure B-81. MPS Leak & Functional
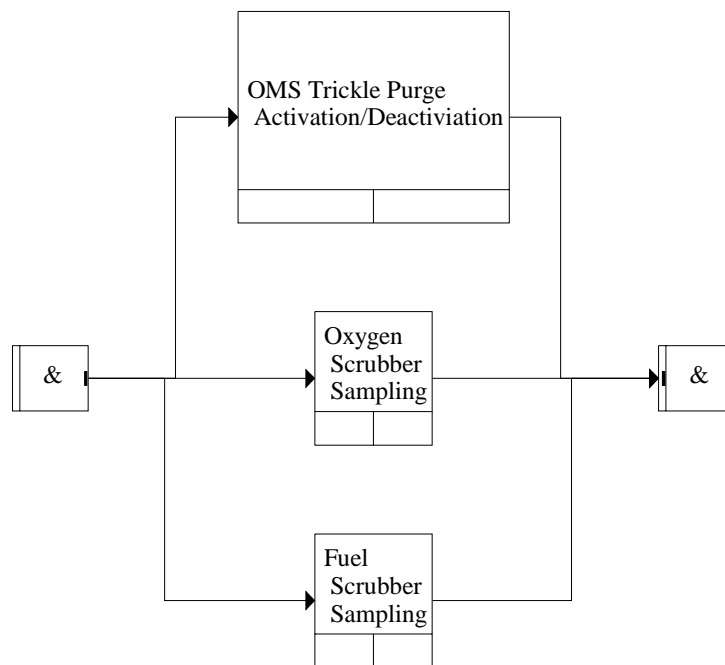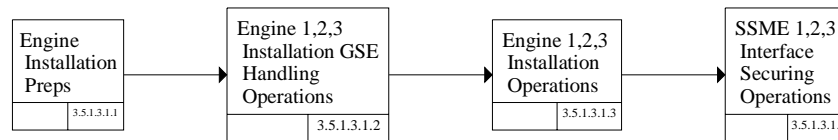

Figure B-82. Monitoring
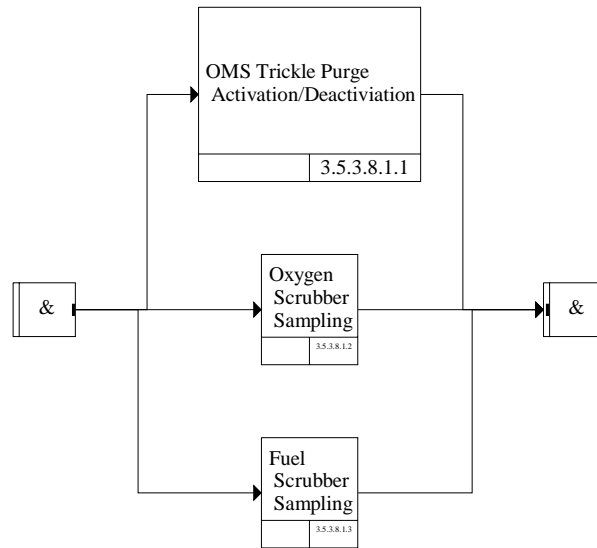
Figure B-83. Monitoring Functions

Figure B-84. Engine Installation Operations
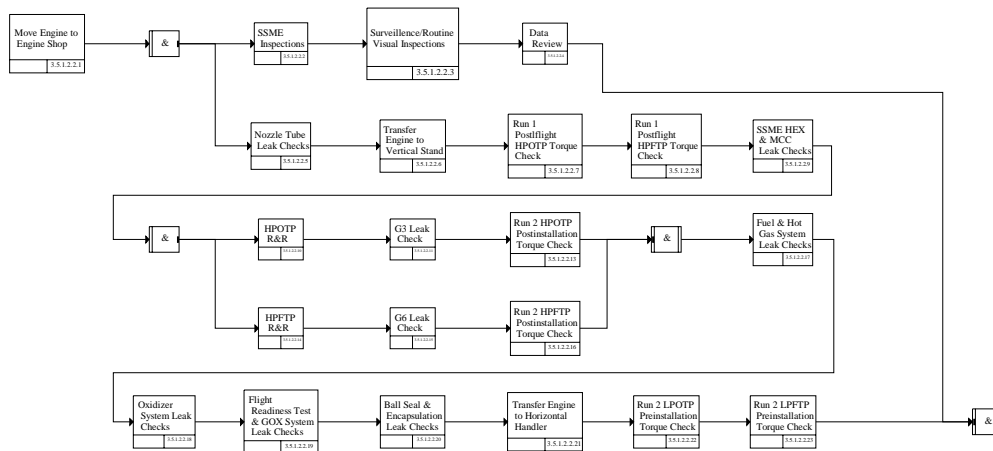
Figure B-85. Existing Engine
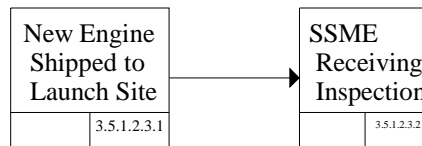
Figure B-86. New Engine

Figure B-87. SSME Removal Operations
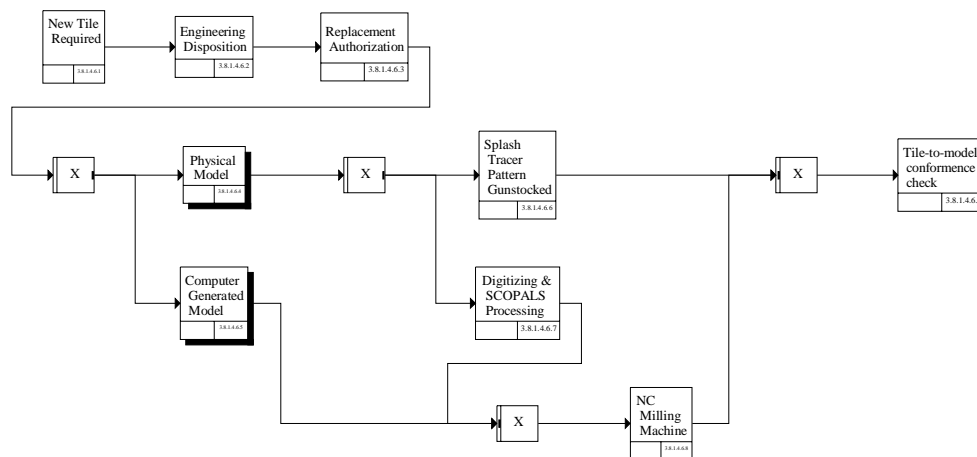
Figure B-88. Make New Tile
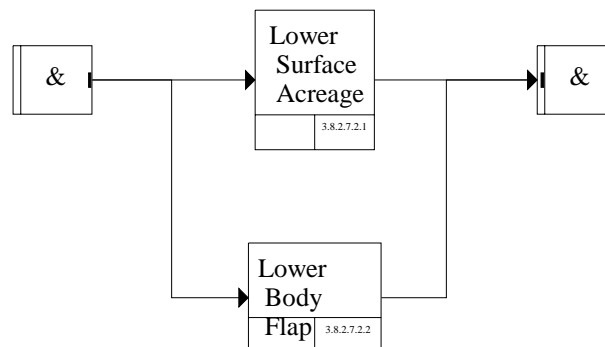
Figure B-89. Lower Aft Fuselage Macro
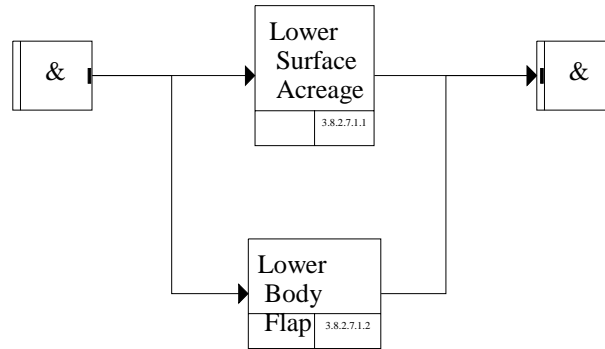
Figure B-90. Lower Aft Fuselage Micro
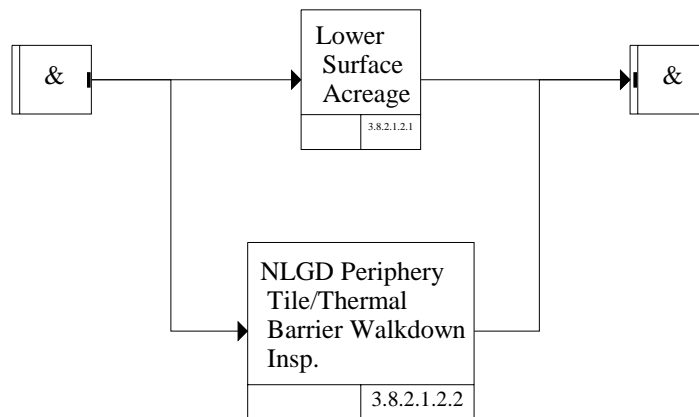
Figure B-91. Lower Forward Fuselage Macro

```
                    ┌──────────────┐
                    │    NLGD      │
                    │   Thermal    │
                    │   Barriers   │
                    ├──────────────┤
                    │    3.8.2.1.1.1│
                    └──────────────┘

                    ┌──────────────┐
                    │   Lower      │
 ┌─────┐            │   Surface    │            ┌─────┐
 │  &  │────────────│   Acreage    │────────────│  &  │
 └─────┘            ├──────────────┤            └─────┘
                    │    3.8.2.1.1.2│
                    └──────────────┘

                    ┌──────────────┐
                    │   Lower      │
                    │   Surface    │
                    │   Acreage    │
                    ├──────────────┤
                    │    3.8.2.1.1.3│
                    └──────────────┘

                    ┌──────────────┐
                    │ NLGD Periphery│
                    │ Tile Roughness│
                    │ Verification  │
                    ├──────────────┤
                    │   3.8.2.1.1.4 │
                    └──────────────┘
```
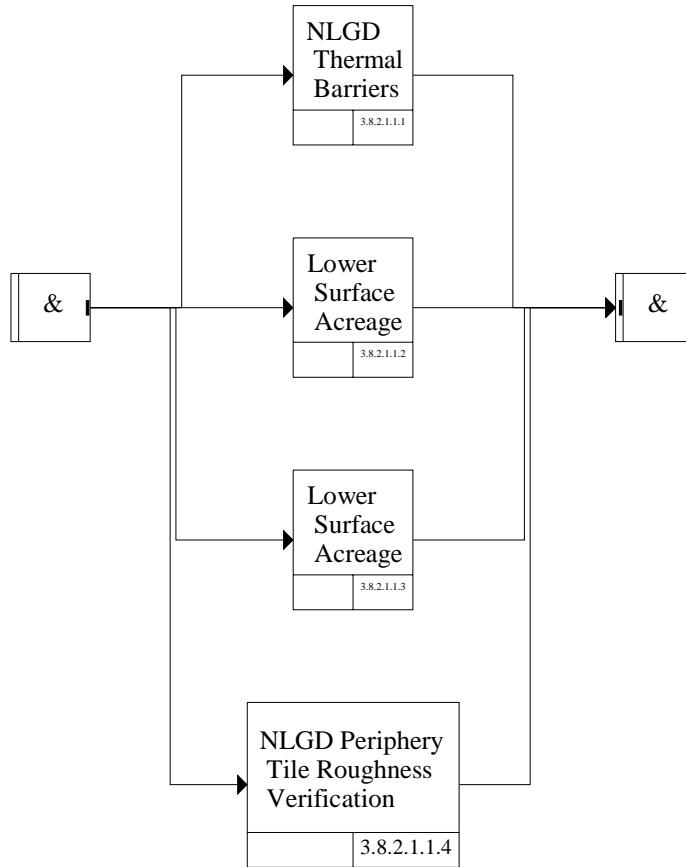
Figure B-92. Lower Forward Fuselage Micro

```
                    ┌──────────────┐
                    │   Lower      │
                    │   Surface    │
                    │   Acreage    │
                    ├──────────────┤
                    │    3.8.2.3.1.1│
                    └──────────────┘
```
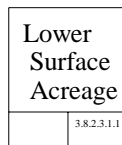
Figure B-93. Lower Midbody Fuselage Macro

```
                    ┌──────────────┐
                    │   Lower      │
                    │   Surface    │
                    │   Acreage    │
                    ├──────────────┤
                    │    3.8.2.3.2.1│
                    └──────────────┘
```
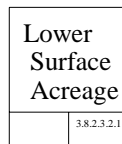
Figure B-94. Lower Midbody Fuselage Micro
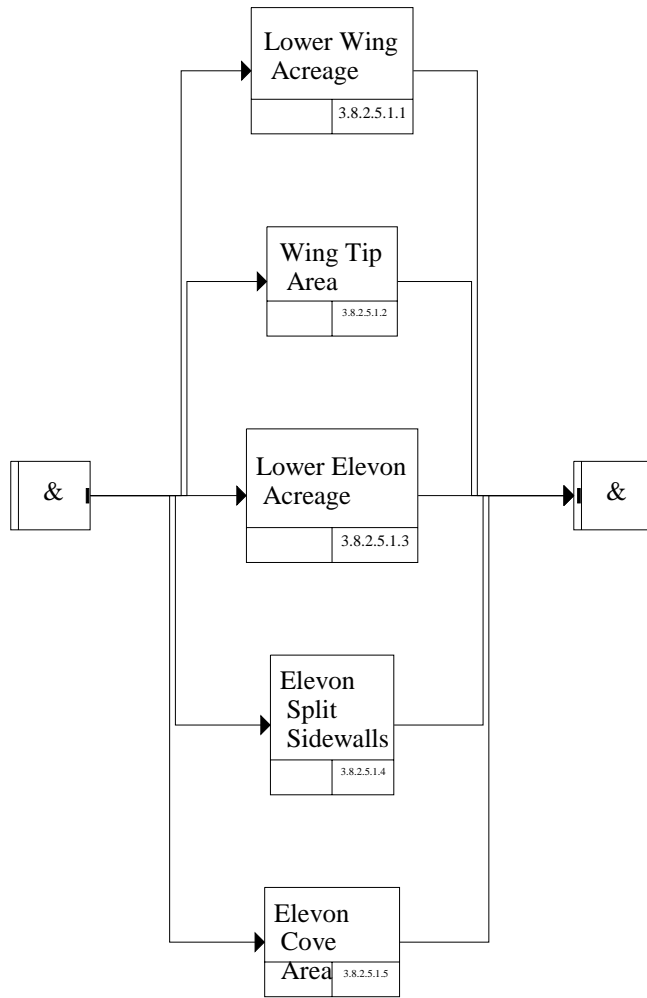
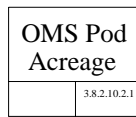**Figure B-95. Lower Wing Macro**
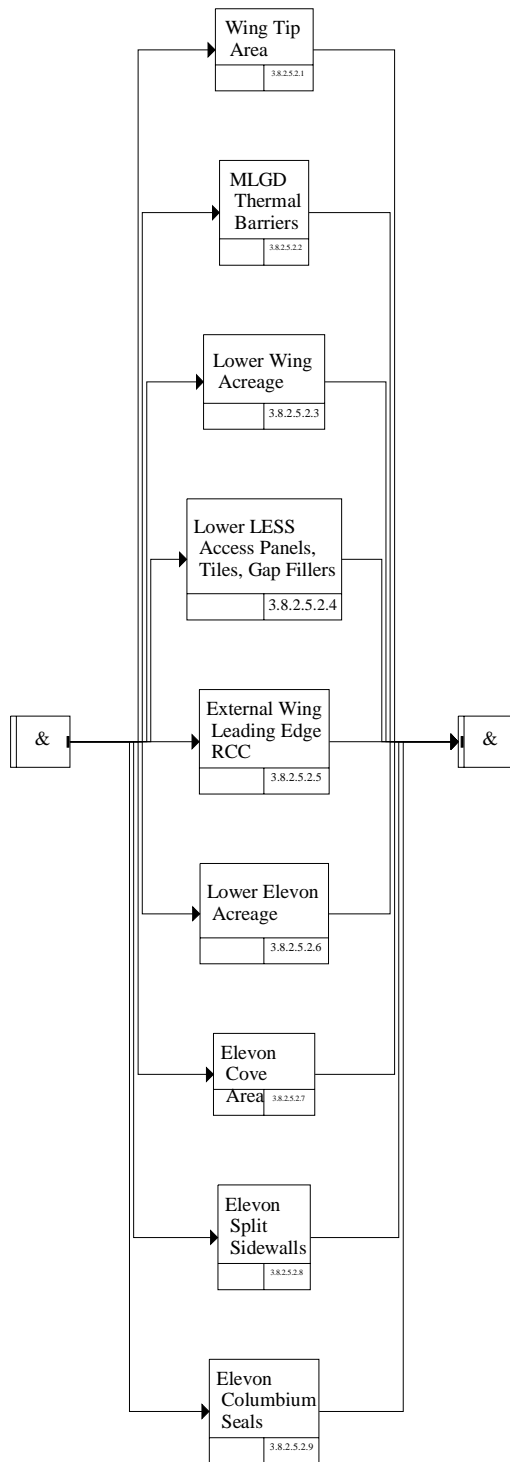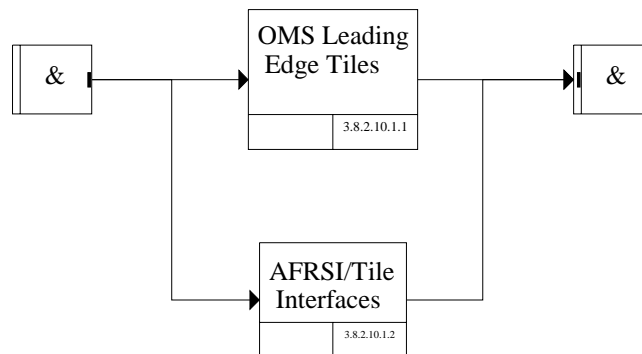
Figure B-96. Lower Wing

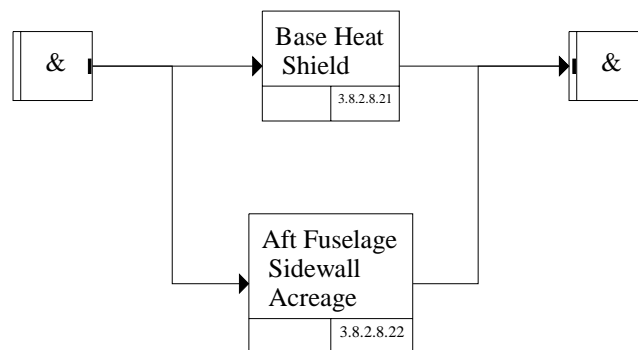**Figure B-97. OMS Pods Macro**

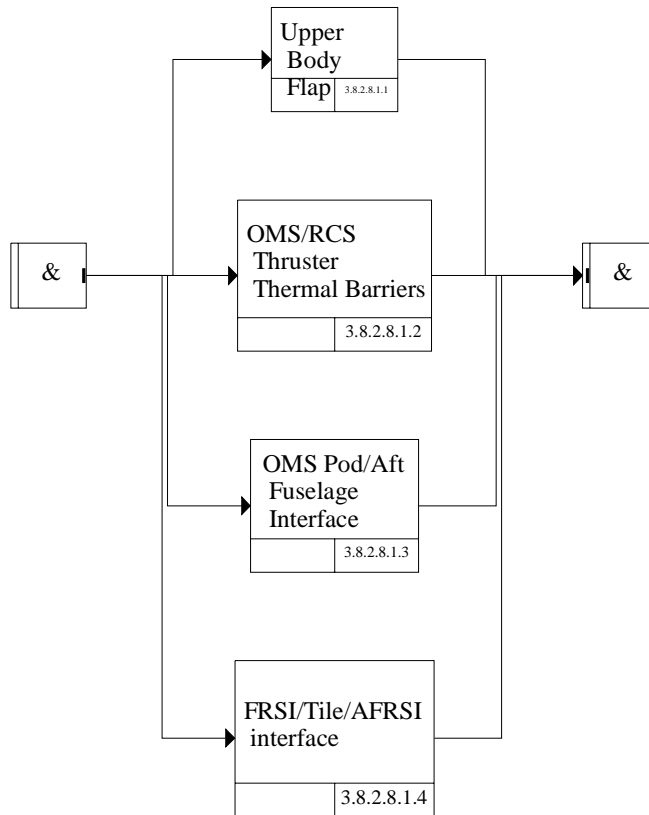**Figure B-98. OMS Pods Micro**

Figure B-99. Upper Aft Fuselage Macro
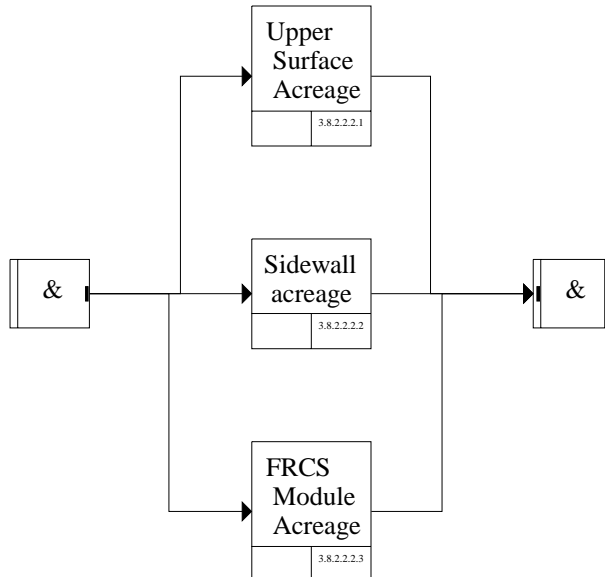
133

Figure B-100. Upper Aft Fuselage Micro

The blocks in the figure read:

- Upper Body Flap — 3.8.2.8.1.1
- OMS/RCS Thruster Thermal Barriers — 3.8.2.8.1.2
- OMS Pod/Aft Fuselage Interface — 3.8.2.8.1.3
- FRSI/Tile/AFRSI interface — 3.8.2.8.1.4

Figure B-101. Upper Forward Fuselage Macro

The blocks in the figure read:

- Upper Surface Acreage — 3.8.2.2.2.1
- Sidewall acreage — 3.8.2.2.2.2
- FRCS Module Acreage — 3.8.2.2.2.3
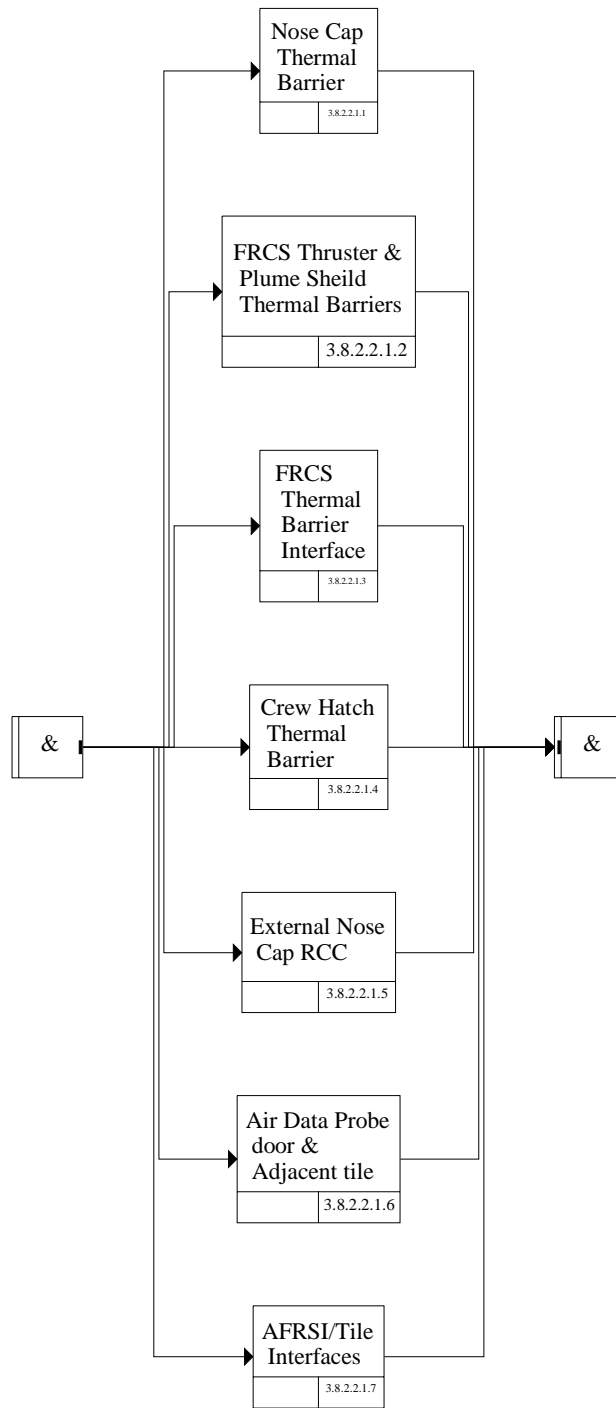
Figure B-102. Upper Forward Fuselage Micro

135
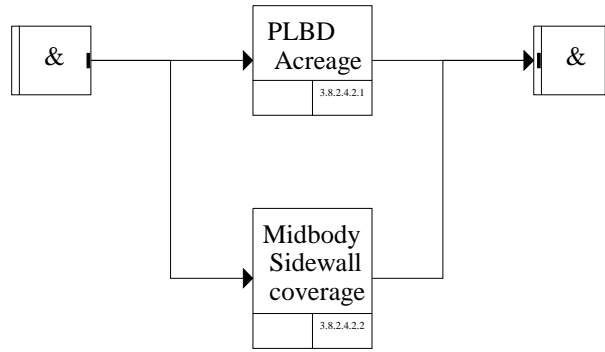
Figure B-103. Upper Midbody Fuselage Macro
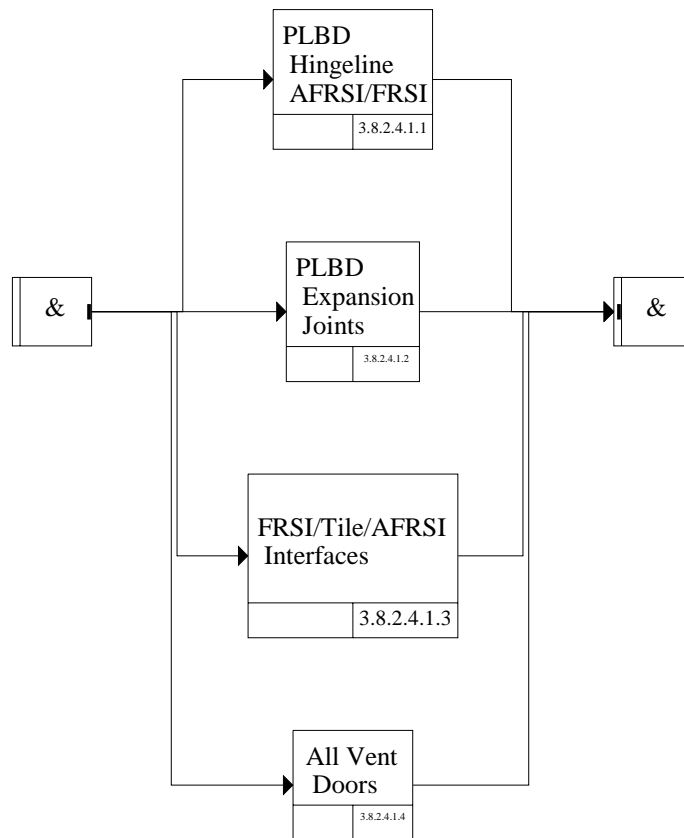
Figure B-104. Upper Midbody Fuselage Micro
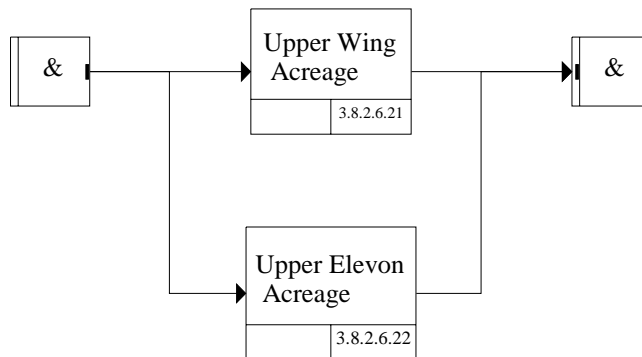
Figure B-105. Upper Wing Macro
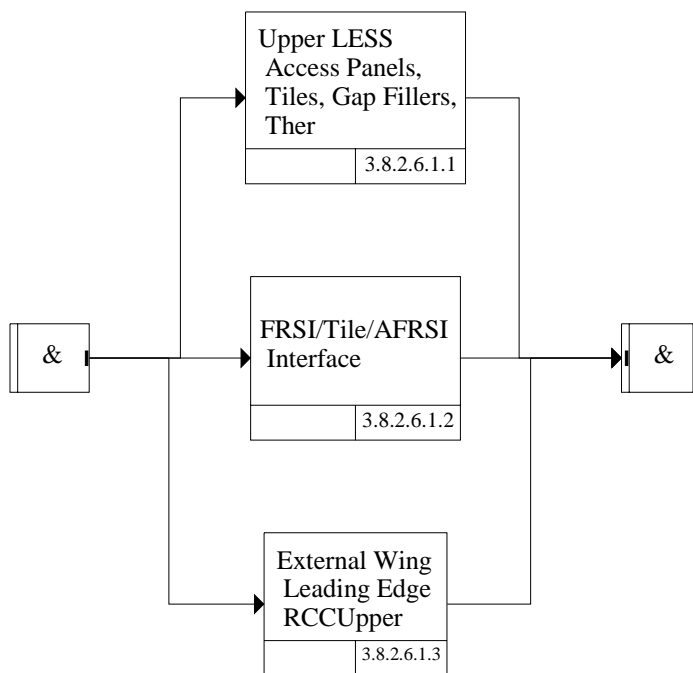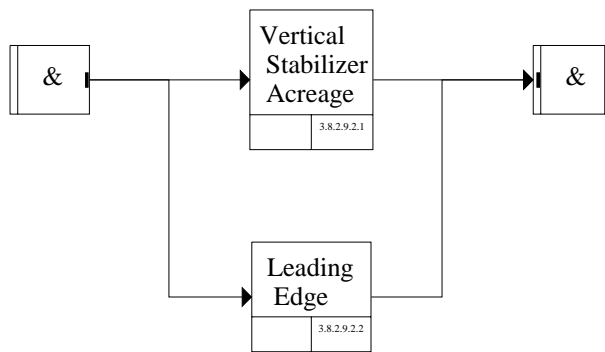

Figure B-106. Upper Wing Micro

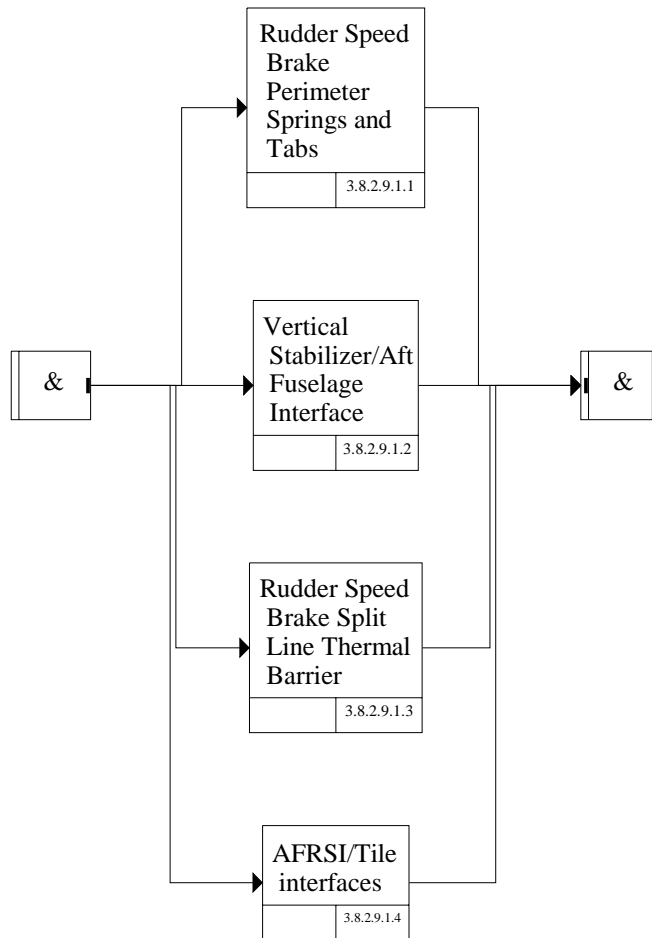**Figure B-107. Vertical Stabilizer Macro**

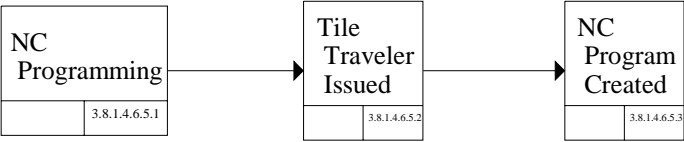**Figure B-108. Vertical Stabilizer Micro**
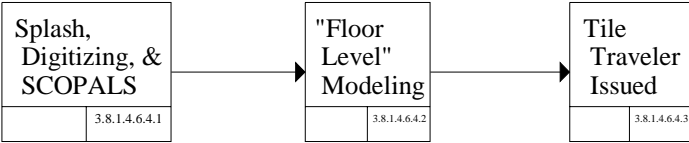
Figure B-109. NC Programming

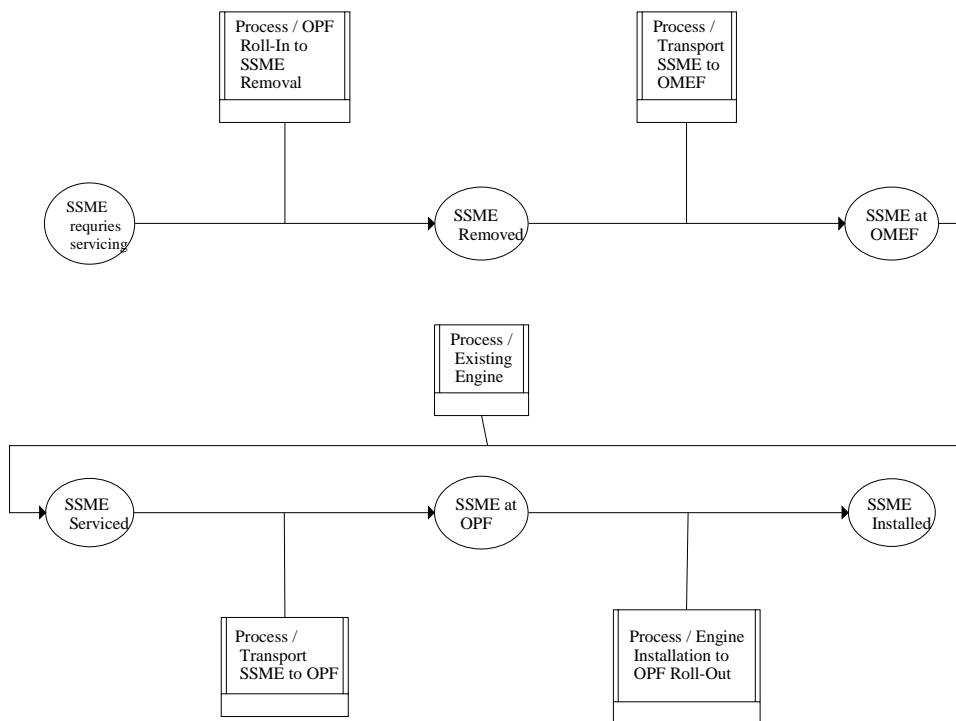**Figure B-110. Physical Model**

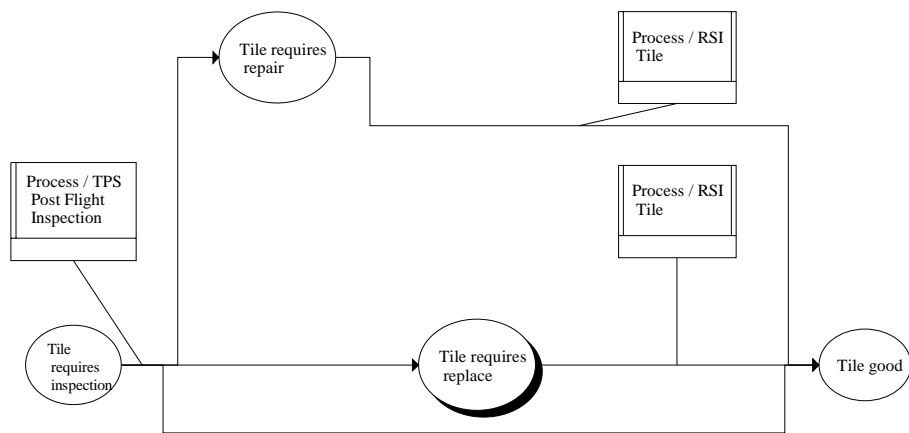**Figure B-111. Orbiter**

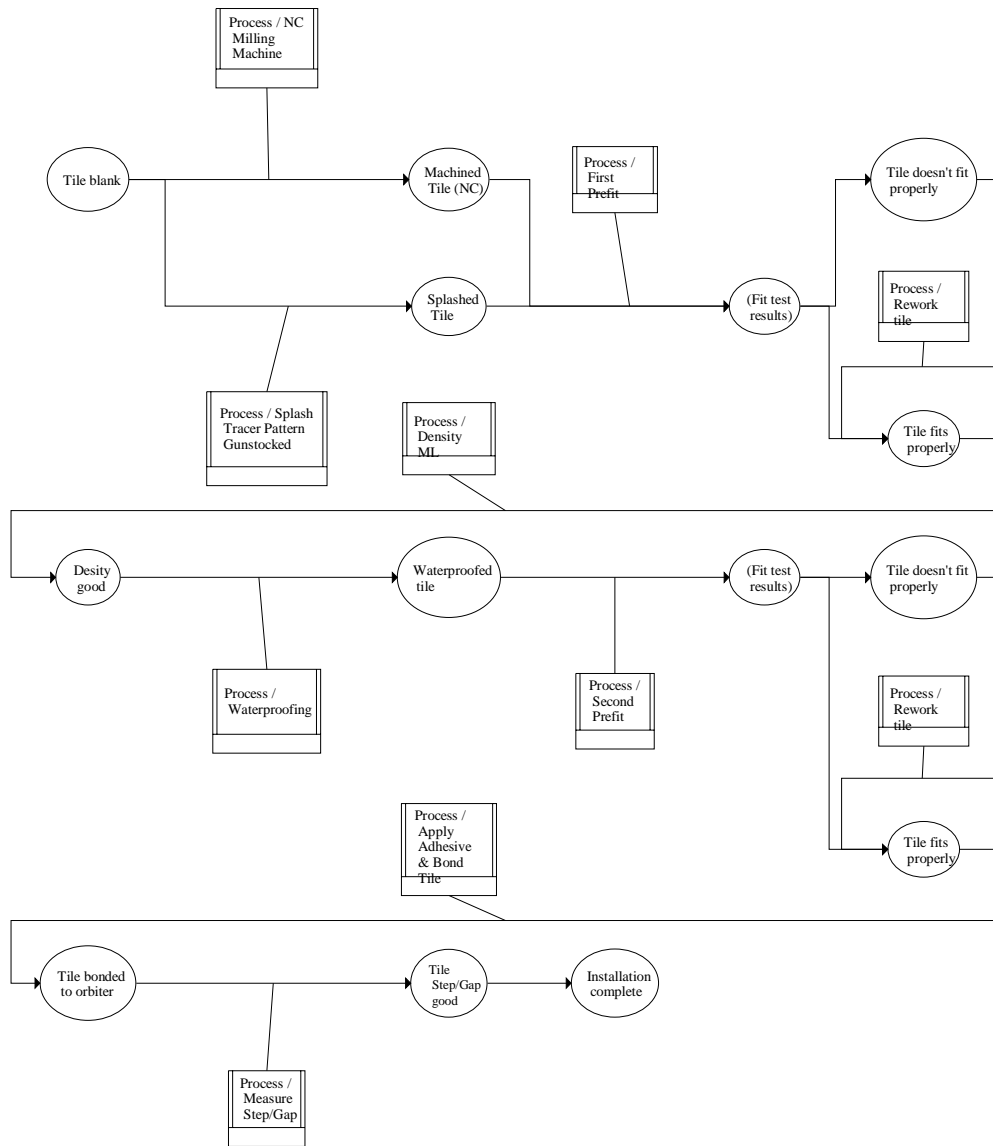**Figure B-112. SSME**

Figure B-113. RSI Tile

Figure B-114. Tile R&R

Appendix C: Future Research

This appendix seeks to expand upon the future research discussed in Chapter 5. This section has been broken into categories with potential areas of analysis listed within each. Some of the subcategories can be taken alone or combined for further research.

Data collection and analysis

Data is available from several sources. NASA has partnered with various agencies such as AFRL and has shared data with them. Within AFRL, several offices may have data collected independently of other sources. A listing of each office working with space shuttle data would be very helpful. Additionally, the current maintenance contract holder, United Space Alliance, would be a good source of information. One of the difficulties experienced was asking for the data using the correct terminology; for example, what NASA calls a work breakdown structure is not necessarily what the researcher has requested. Some areas of future research within this area are as follows:

- Develop a user friendly information system to capture both component and subsystem level logistics information (MTTF, Repair Time, failure rate distributions, etc) from research and development through Concept Refinement and Technology Development (Milestone B) to enable Simulation Based R&D and Simulation Based Acquisition model development.

- Develop methodology to collect and document component and subsystem level logistics information (MTTF, Repair Time, failure rate distributions, etc) from past, present and future reusable space vehicle operations to enable Simulation Based R&D and Simulation Based Acquisition model development.

- Identify, quantify, and incorporate into conceptual model space shuttle's "unscheduled/troubleshooting" activities (propulsion, power management, thermal protection, etc…).

System Comparisons

The space shuttle is not the only vehicle to be used as a baseline. Therefore it is necessary to look at the other baselines on the aircraft side of the spectrum. Also, any simulations existing for aircraft systems would be of interest and should be examined. Another area of interest would be the logistics surrounding expendable launch vehicles (ELV).

– Compare and contrast the ground facility/logistics requirements for rocket and air-breathing propulsion systems for use on reusable space vehicles (maintenance, fuel, etc...).

– Compare and contrast the ground facility/logistics requirements for current and potential future thermal protection systems.

– Investigate the difference in logistics/maintenance requirements for manned and unmanned reusable launch vehicles.

– Investigate the ground facility/logistics requirements for the aircraft selected as the baseline. Locate and analyze any existing simulations.

– Investigate the ground facility/logistics requirements for ELVs. Locate and analyze any existing simulations.

Simulation Generation

– Develop simulation modules for "design disciplines" identified in this document (propulsion, power management, thermal protection, etc…) based upon planned/scheduled maintenance.

– Develop simulation modules for "design disciplines" identified in this document (propulsion, power management, thermal protection, etc…) based upon unscheduled/troubleshooting activities.

Investigate other simulations

– Compare and contrast simulations under development by NASA, AFRL, and other government agencies. Examine modules included, level of detail, and reasoning behind development. Look for level of detail, systems included, and precedence/flow logic. Then compare to the baseline conceptual model in this research and to the simulations being investigated.

  - Compare and contrast NASA's Shuttle Op's 1.0 to existing AFRL and contractor simulations.

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Vita

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14. ABSTRACT

   Modeling efforts for future space operation vehicles at the United States Air Force Research Lab's Air Vehicles Directorate have been focused towards the in flight mission. To better serve the research and development effort, a simulation of the ground operations is required allowing for trade-offs within turnaround operations and between the components that drive those procedures. However, before a simulation can be developed a conceptual model must be generated to guide the model building process.

   This research provides a baseline conceptual model for reusable space vehicles based on the space shuttle as the only operational vehicle of its kind. The model is built utilizing the Integrated Definition (IDEF) methodology, specifically IDEF3. IDEF3 is focused towards process-viewpoint diagramming and layout. The model is developed using the hierarchical development capabilities of the IDEF3 methodology and is broken into modules allowing for greater reuse and usability.

   This model captures the scheduled maintenance performed to turnaround the space shuttle for the next launch but does not contain every activity. The idea was to capture the baseline activities that may be found in future Reusable Space Vehicles and provide a description of what happens at Kennedy Space Center when preparing the space shuttle for the next launch.

15. SUBJECT TERMS
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